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Discretion Rather Than Rules? When Is Discretionary Policymaking Better Than the Timeless Perspective?*

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Discretionary monetary policy produces a dynamic loss in the New Keynesian model in the presence of cost-push shocks. The possibility to commit to a specific policy rule can increase welfare. A number of authors since Woodford (1999) have argued in favor of a timeless-perspective rule as an optimal policy. The short-run costs associated with the timeless perspective are neglected in general, however. Rigid prices, relatively impatient households, a high preference of policymakers for output stabilization, and a deviation from the steady state all worsen the performance of the timeless-perspective rule and can make it inferior to discretion.

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1. Introduction

Kydland and Prescott (1977) showed that rule-based policymaking can increase welfare. The timeless perspective proposed by Woodford (1999) represents a prominent modern form of such a rule in

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monetary policy analysis. It helps to overcome not only the traditional inflation bias in the sense of Barro and Gordon (1983a, 1983b) but also the stabilization bias, a dynamic loss stemming from cost-push shocks in the New Keynesian model as described in Clarida, Galí, and Gertler (1999). It is, however, associated with short-run costs that may be larger than the long-run gains from commitment.

After deriving a formal condition for the superiority of discretion over the timeless-perspective rule, this paper investigates the influence of structural and preference parameters on the performance of monetary policy both under discretion and the timeless perspective in the sense of Woodford (1999). Discretion gains relative to the timeless-perspective rule—i.e., the short-run losses become relatively more important—if the private sector behaves less forward looking or if the monetary authority puts a greater weight on output-gap stabilization. For empirically reasonable values of price stickiness, the relative gain from discretion rises with stickier prices. A fourth parameter which influences the relative gains is the persistence of shocks: Introducing serial correlation into the model only strengthens the respective relative performance of policies in the situation without serial correlation in shocks. In particular, we show conditions for each parameter under which discretion performs strictly better than the timeless-perspective rule.

Furthermore, the framework of short-run losses and long-run gains also allows explaining why an economy that is sufficiently far away from its steady state suffers rather than gains from implementing the timeless-perspective rule. In general, this paper uses unconditional expectations of the loss function as welfare criterion, in line with most of the literature. The analysis of initial conditions, however, requires reverting to expected losses conditional on the initial state of the economy because unconditional expectations of the loss function implicitly treat the economy's initial conditions as stochastic. Altogether, in the normal New Keynesian model, all conditions for the superiority of discretion need not be as adverse as one might suspect—in particular, if the initial output-gap situation is taken into account.

The following section 2 presents the canonical New Keynesian model. Section 3.1 explains the relevant welfare criteria. The analytical solution in section 3.2 is followed by simulation results and a thorough economic interpretation of the performance of policies under discretion and the timeless perspective. Section 3.4 completes the discussion of Woodford's timeless perspective by looking at the effects of initial conditions before section 4 concludes.

2. New Keynesian Model

The New Keynesian or New Neoclassical Synthesis model has become the standard toolbox for modern macroeconomics. While there is some debate about the exact functional forms, the standard setup consists of a forward-looking Phillips curve, an intertemporal IS curve, and a welfare function.[1] Following, e.g., Walsh (2003), the New Keynesian Phillips curve based on Calvo (1983) pricing is given by

$$\pi_t = \beta E_t \pi_{t+1} + \alpha y_t + u_t \tag{1}$$

with

$$\alpha \equiv \frac{(1-\zeta)(1-\beta\zeta)}{\zeta}. \tag{2}$$

π_t denotes inflation, E_t the expectations operator conditional on information in period t, y_t the output gap, and u_t a stochastic shock term that is assumed to follow a stationary AR(1) process with AR parameter ρ and innovation variance σ^2. While the output gap refers to the deviation of actual output from natural or flexible-price output, u_t is often interpreted as a cost-push shock term that captures time-varying distortions from consumption or wage taxation or markups in firms' prices or wages. It is the source of the stabilization bias. $0 < \beta < 1$ denotes the (private sector's) discount factor and $0 \leq \zeta < 1$ is the constant probability that a firm is not able to reset its price in period t. A firm's optimal price depends on current and (for $\zeta > 0$) future real marginal costs, which are assumed to be proportional to the respective output gap.[2] Hence, ζ and α reflect the degree of price rigidity in this model, which is increasing in ζ and decreasing in α.

[1] Depending on the purpose of their paper, some authors directly use an instrument rule or a targeting rule without explicitly maximizing some welfare function.

[2] In (1), the proportionality factor is set equal to 1.

The policymaker's objective at an arbitrary time $t = 0$ is to minimize

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t L_t \qquad \text{with} \quad L_t = \pi_t^2 + \omega y_t^2, \tag{3}$$

where $\omega \geq 0$ reflects the relative importance of output-gap variability in policymaker preferences. We assume zero to be the target value of both inflation and the output gap. While the former assumption is included only for notational simplicity and without loss of generality, the latter is crucial for the absence of a traditional inflation bias in the sense of Barro and Gordon (1983a, 1983b).

The New Keynesian model also includes an aggregate demand relationship based on consumers' intertemporal optimization in the form of

$$y_t = E_t y_{t+1} - b(R_t - E_t \pi_{t+1}) + v_t, \tag{4}$$

where R_t is the central bank's interest rate instrument and v_t is a shock to preferences, government spending, or the exogenous natural-rate value of output, for example.[3] The parameter $b > 0$ captures the output-gap elasticity with respect to the real interest rate. Yet, for distinguishing between the timeless-perspective and discretionary solutions, it is sufficient to assume that the central bank can directly control π_t as an instrument. Hence, the aggregate demand relationship can be neglected below.[4]

2.1 Model Solutions

If the monetary authority neglects the impact of its policies on inflation expectations and reoptimizes in each period, it conducts monetary policy under *discretion*. This creates both the Barro and Gordon (1983a, 1983b) inflation bias for positive output-gap targets and the Clarida, Galí, and Gertler (1999) stabilization bias caused by cost-push shocks. To concentrate on the second source of dynamic losses

[3] v_t is generally referred to as a *demand* shock. But in this model, y_t reflects the output *gap* and not output alone. Hence, shocks to the flexible-price level of output are also included in v_t. See, e.g., Woodford (2003, p. 246).

[4] Formally, adding (4) as a constraint to the optimization problems below gives a value of zero to the respective Lagrangian multiplier.

in this model, a positive inflation bias is ruled out by assuming an output-gap target of zero in the loss function (3). Minimizing (3) subject to (1) and to given inflation expectations $E_t\pi_{t+1}$ results in the Lagrangian

$$\Lambda_t = \pi_t^2 + \omega y_t^2 - \lambda_t(\pi_t - \beta E_t\pi_{t+1} - \alpha y_t - u_t) \qquad \forall\ t = 0, 1, 2, \ldots. \tag{5}$$

The first-order conditions

$$\frac{\partial \Lambda_t}{\partial y_t} = 2\omega y_t + \alpha\lambda_t = 0$$
$$\frac{\partial \Lambda_t}{\partial \pi_t} = 2\pi_t - \lambda_t = 0$$

imply

$$\pi_t = -\frac{\omega}{\alpha} y_t. \tag{6}$$

If instead the monetary authority takes the impact of its actions on expectations into account and possesses an exogenous possibility to credibly commit itself to some future policy, it can minimize the loss function (3) over an enhanced opportunity set. Hence, the resulting *commitment solution* must be at least as good as the one under discretion. The single-period Lagrangian (5) changes to

$$\Lambda = E_0 \sum_{t=0}^{\infty} \beta^t \big[\big(\pi_t^2 + \omega y_t^2\big) - \lambda_t(\pi_t - \beta\pi_{t+1} - \alpha y_t - u_t)\big]. \tag{7}$$

This yields as first-order conditions

$$\frac{\partial \Lambda}{\partial y_t} = 2\omega y_t + \alpha\lambda_t = 0, \quad t = 0, 1, 2, \ldots,$$
$$\frac{\partial \Lambda}{\partial \pi_t} = 2\pi_t - \lambda_t = 0, \quad t = 0,$$
$$\frac{\partial \Lambda}{\partial \pi_t} = 2\pi_t - \lambda_t + \lambda_{t-1} = 0, \quad t = 1, 2, \ldots,$$

implying

$$\pi_t = -\frac{\omega}{\alpha} y_t, \qquad t = 0 \quad \text{and} \tag{8}$$

$$\pi_t = -\frac{\omega}{\alpha} y_t + \frac{\omega}{\alpha} y_{t-1}, \qquad t = 1, 2, \ldots . \tag{9}$$

The commitment solution improves the short-run output/inflation trade-off faced by the monetary authority because short-run price dynamics depend on expectations about the future. Since the authority commits to a history-dependent policy in the future, it is able to optimally spread the effects of shocks over several periods. The commitment solution also enables the policymaker to reap the benefits of discretionary policy in the initial period without paying the price in terms of higher inflation expectations, since these are assumed to depend on the future commitment to (9). Indeed, optimal policy is identical under commitment and discretion in the initial period. Nevertheless, the equilibrium outcomes for inflation and the output gap under the two policy regimes differ, as they also depend on inflation expectations and thus the prevailing policy regime. In a recent paper, Dennis and Söderström (2006) compare the welfare gains from commitment over discretion under different scenarios.

However, the commitment solution suffers from time inconsistency in two ways: First, by switching from (9) to (6) in any future period, the monetary authority can exploit given inflation expectations and gain in the respective period. Second, the monetary authority knows at $t = 0$ that applying the same optimization procedure (7) in the future implies a departure from today's optimal plan, a feature McCallum (2003, p. 4) calls "strategic incoherence."

To overcome the second form of time inconsistency and thus gain true credibility, many authors since Woodford (1999) have proposed the concept of policymaking under the *timeless perspective*: The optimal policy in the initial period should be chosen such that it would have been optimal to commit to this policy at a date far in the past, not exploiting given inflation expectations in the initial period.[5] This implies neglecting (8) and applying (9) in *all* periods, not just in $t = 1, 2, \ldots$:

[5]Woodford (1999) compares this "commitment" to the "contract" under John Rawls's veil of uncertainty. In a recent contribution, Loisel (2008) endogenizes

$$\pi_t = -\frac{\omega}{\alpha}y_t + \frac{\omega}{\alpha}y_{t-1}, \qquad t = 0, 1, \dots . \tag{10}$$

Hence, the only difference to the commitment solution lies in the different policy in the initial period, unless the economy starts from its steady state with $y_{-1} = 0$.[6] But since the commitment solution is by definition optimal for (7), this difference causes a loss of the timeless-perspective policy compared with the commitment solution. If this loss is greater than the gain from the commitment solution (COM) over discretion, rule-based policymaking under the timeless perspective (TP) causes larger losses than policy under discretion (DIS):

$$L_{TP} - L_{COM} > L_{DIS} - L_{COM} \qquad \Leftrightarrow \qquad L_{TP} > L_{DIS}. \tag{11}$$

The central aim of the rest of this paper is to compare the losses from TP and DIS.

2.2 Minimal State Variable (MSV) Solutions

Before we are able to calculate the losses under the different policy rules, we need to determine the particular equilibrium behavior of the economy, which is given by the New Keynesian Phillips curve (1)[7] and the respective policy rule, i.e., DIS (6) or TP (10). Following McCallum (1999), the minimal state variable (MSV) solution to each model represents the rational-expectations solution that excludes bubbles and sunspots.

Under discretion, u_t is the only relevant state variable in (1) and (6):

$$\pi_t = \beta E_t \pi_{t+1} + \alpha y_t + u_t$$
$$\pi_t = -\frac{\omega}{\alpha}y_t,$$

the timeless perspective for certain calibrated parameter values following the reputation mechanism in Barro and Gordon (1983b).

[6]Due to the history dependence of (10), the different initial policy has some influence on the losses in subsequent periods, too.

[7]Without loss of generality but to simplify the notation, the MSV solutions are derived based on (1) without reference to (2). The definition of α in (2) is substituted into the MSV solutions for the simulation results in section 3.3.

so the conjectured solution is of the form

$$\pi_{t,DIS} = \phi_1 u_t$$
$$y_{t,DIS} = \phi_2 u_t.$$

Since $E_t\pi_{t+1} = \phi_1 \rho u_t$ in this case, the MSV solution is given by

$$\pi_{t,DIS} = \frac{\omega}{\omega(1-\beta\rho)+\alpha^2}u_t \tag{12}$$
$$y_{t,DIS} = \frac{-\alpha}{\omega(1-\beta\rho)+\alpha^2}u_t. \tag{13}$$

Under the timeless perspective, y_{t-1} and u_t are the relevant state variables from (1) and (10):

$$\pi_t = \beta E_t\pi_{t+1} + \alpha y_t + u_t$$
$$\pi_t = -\frac{\omega}{\alpha}y_t + \frac{\omega}{\alpha}y_{t-1}.$$

Hence, the conjectured solution becomes

$$\pi_{t,TP} = \phi_{11}y_{t-1} + \phi_{12}u_t \tag{14}$$
$$y_{t,TP} = \phi_{21}y_{t-1} + \phi_{22}u_t. \tag{15}$$

After some calculations,[8] the resulting MSV solution is described by

$$\pi_{t,TP} = \frac{\omega(1-\delta)}{\alpha}y_{t-1} + \frac{1}{\gamma-\beta(\rho+\delta)}u_t \tag{16}$$
$$y_{t,TP} = \delta y_{t-1} - \frac{\alpha}{\omega(\gamma-\beta(\rho+\delta))}u_t, \tag{17}$$

with $\gamma \equiv 1+\beta+\frac{\alpha^2}{\omega}$ and $\delta \equiv \frac{\gamma-\sqrt{\gamma^2-4\beta}}{2\beta}$. Given these MSV solutions, we are now able to evaluate the relative performance of monetary policy under discretion and the timeless-perspective rule.

[8]These calculations include a quadratic equation in ϕ_{21}, of which only one root, $0 < \delta < 1$, is relevant according to both the stability and MSV criteria.

3. Policy Evaluation

3.1 Welfare Criteria

3.1.1 Unconditional Expectations

The standard approach to evaluate monetary policy performance is to compare average values for the period loss function—i.e., values of the unconditional expectations of the period loss function in (3), denoted as $E[L_t]$. We follow this approach for the analysis of the influence of preference and structural parameters mainly because it is very common in the literature[9] and allows an analytical solution. However, it includes several implicit assumptions.

First, π_t and y_t need to be covariance stationary. This is not a problem in our setup since u_t is stationary by assumption and $0 < \delta < 1$ is chosen according to the stability criterion; see footnote 8. Second, using unconditional expectations of L_t implies treating the initial conditions as stochastic (see, e.g., King and Wolman 1999, p. 377) and thus averages over all possible initial conditions. Third, the standard approach treats all periods in the same way as $E[L_t] = E[L_{t+j}]$ for all $j \geq 0$. This may influence the precise parameter values for which DIS performs better than TP in section 3.3, but it only strengthens the general argument with respect to the influence of β, as will be shown below.

3.1.2 Conditional Expectations

At the same time, using unconditional expectations impedes an investigation of the effects of specific initial conditions and transitional dynamics to the steady state on the relative performance of policy rules. For this reason and to be consistent with the microfoundations of the New Keynesian model, Kim and Levin (2005), Kim et al. (2008), and Schmitt-Grohé and Uribe (2004) argue in favor of conditional expectations as the relevant welfare criterion. If future outcomes are discounted—i.e., $\beta < 1$—the use of conditional

[9]See, e.g., various articles in the conference volume by Taylor (1999) and Clarida, Galí, and Gertler (1999), Jensen and McCallum (2002), and Woodford (1999).

expectations—i.e., $\mathcal{L}$ in (3)—as welfare criterion implies that short-run losses from TP become relatively more important to the long-run gains compared with the evaluation with unconditional expectations.

Both concepts can be used to evaluate the performance of monetary policy under varying parameter values, and the results are qualitatively equivalent. Besides its popularity and analytical tractability, the choice of unconditional expectations as the general welfare measure has a third advantage: by implicitly averaging over all possible initial conditions and treating all periods the same, we can evaluate policies for all current and future periods and thus consider the policy problem from a "truly timeless" perspective in the sense of Jensen (2003), which does not bias our results in favor of discretionary policymaking. Only the analysis of the effects of different initial conditions requires reverting to conditional expectations.

3.2 Analytical Solution

In principle, the relative performance of DIS and TP can be solved analytically if closed-form solutions for the unconditional expectations of the period loss function are available. This is possible, since

$$L_i = E[L_{t,i}] = E\left[\pi_{t,i}^2\right] + \omega E\left[y_{t,i}^2\right], \quad i \in \{DIS, TP\} \tag{18}$$

from (3) and the MSV solutions in section 2.2 determine the unconditional variances $E[\pi_{t,i}^2]$ and $E[y_{t,i}^2]$. The MSV solution under discretion, (12) and (13) with u_t as the only state variable and $E[u_t^2] = \frac{1}{1-\rho^2}\sigma^2$, gives the relevant welfare criterion

$$\begin{aligned} L_{DIS} &= \left[\frac{\omega}{\omega(1-\beta\rho)+\alpha^2}\right]^2 \frac{1}{1-\rho^2}\ \sigma^2 \\ &\quad + \omega\left[\frac{-\alpha}{\omega(1-\beta\rho)+\alpha^2}\right]^2 \frac{1}{1-\rho^2}\ \sigma^2 \\ &= \frac{\omega(\omega+\alpha^2)}{[\omega(1-\beta\rho)+\alpha^2]^2} \cdot \frac{1}{1-\rho^2}\ \sigma^2. \end{aligned} \tag{19}$$

For the timeless perspective, the MSV solution (16) and (17) depends on two state variables, y_{t-1} and u_t. From the conjectured solution in (14) and (15), we have

$$E\left[\pi_{t,TP}^2\right] = \phi_{11}^2 E\left[y_{t-1}^2\right] + \phi_{12}^2 E\left[u_t^2\right] + 2\phi_{11}\phi_{12}E[y_{t-1}u_t]$$
$$E\left[y_{t,TP}^2\right] = \phi_{21}^2 E\left[y_{t-1}^2\right] + \phi_{22}^2 E\left[u_t^2\right] + 2\phi_{21}\phi_{22}E[y_{t-1}u_t]. \quad (20)$$

These two equations are solved and plugged into (18) in the appendix. The result is

$$L_{TP} = \frac{2\omega(1-\delta)(1-\rho) + \alpha^2(1+\delta\rho)}{\omega(1-\delta^2)(1-\delta\rho)[\gamma - \beta(\delta+\rho)]^2} \cdot \frac{1}{1-\rho^2}\,\sigma^2. \quad (21)$$

Hence, discretion is superior to the timeless-perspective rule if

$$L_{DIS} < L_{TP} \quad \Leftrightarrow \quad \frac{\omega(\omega+\alpha^2)}{[\omega(1-\beta\rho)+\alpha^2]^2} < \frac{2\omega(1-\delta)(1-\rho) + \alpha^2(1+\delta\rho)}{\omega(1-\delta^2)(1-\delta\rho)[\gamma - \beta(\delta+\rho)]^2}$$
$$\Leftrightarrow \quad RL \equiv L_{TP}/L_{DIS} - 1 > 0. \quad (22)$$

Equation (22) allows analytical proofs of several intuitive arguments: First, the variance of cost-push shocks $\frac{1}{1-\rho^2}\sigma^2$ affects the magnitude of absolute losses in (19) and (21) but has no effect on the relative loss RL because it cancels out in (22). Second, economic theory states that with perfectly flexible prices, i.e., $\zeta = 0$ and $\alpha \to \infty$, the short-run Phillips curve is vertical at $y_t = 0$. In this case, the short-run output/inflation trade-off and hence the source of the stabilization bias disappears completely and no difference between DIS, COM, and TP can exist.

Third, if the society behaves as an "inflation nutter" (King 1997) and only cares about inflation stabilization—i.e., $\omega = 0$—inflation deviates from the target value neither under discretion nor under rule-based policymaking. This behavior eliminates the stabilization bias because the effect of shocks cannot be spread over several periods. Shocks always enter the contemporaneous output gap completely, but they do not cause welfare losses for an inflation nutter. Furthermore, the initial conditions do not matter, since y_{-1} receives a weight of 0 in (10) and no short-run loss arises. The last two statements are summarized in the following proposition.

PROPOSITION 1. *Discretion and Woodford's timeless perspective are equivalent for*

(i) perfectly flexible prices or
(ii) inflation-nutter preferences.

Proof.

(i) $\lim_{\alpha \to \infty} RL = 0$.
(ii) $\lim_{\omega \to 0} RL = 0$.

Finally, proposition 2 states that discretion is not always inferior to Woodford's timeless perspective. If the private sector discounts future developments at a larger rate—i.e., β decreases—firms care less about optimal prices in the future when they set their optimal price today. Hence, the potential to use future policies to spread the effects of a current shock via the expectations channel decreases. Therefore, the loss from the stabilization bias under DIS, where this potential is not exploited (i.e., the long-run gains $L_{DIS} - L_{COM}$), also decreases with smaller β, while the short-run costs from TP, $L_{TP} - L_{COM}$, remain unaffected under rule (10). In the extreme case of $\beta = 0$, expectations are irrelevant in the Phillips curve (1) and the source of the stabilization bias disappears. If the reduction in the long-run gain is sufficiently large, conditions (11) and (22) are fulfilled.

PROPOSITION 2. *There exists a discount factor β small enough such that discretion is superior to Woodford's timeless perspective as long as some weight is given to output stabilization and prices are not perfectly flexible.*

Proof. RL is continuous in β because stability requires $0 \leq \delta, \rho < 1$. Furthermore, $\lim_{\beta \to 0} RL = \frac{[\alpha^2+2(1-\rho)\omega+(1+\rho)\omega](\alpha^2+\omega)}{(\alpha^2+2\omega)[\alpha^2+(1-\rho)\omega]} - 1 > 0$ for $\omega > 0 \wedge \alpha < \infty$.

In principle, (22) could be used to look at the influence of structural (ζ, ρ) and preference (β, ω) parameters on the relative performance of monetary policy under discretion and the timeless-perspective rule more generally.[10] Unfortunately, (22) is too complex

[10]Please note that, conceptually, it would be nonsense to compare one policy over several values of a preference parameter. Here, however, we always compare two policies (DIS and TP), holding all preference and structural parameters constant.

Table 1. Parameter Values Used in the Benchmark Model and Common in the Literature

Parameter	$\boldsymbol{\beta}$	$\boldsymbol{\omega}$	$\boldsymbol{\zeta}$	$\boldsymbol{\alpha}$	$\boldsymbol{\rho}$
Benchmark Model	0.99	0.0625	0.8722	0.02	0
Range in the Literature	0.97–1	0.01–0.25	0.73–0.91	0.01–0.1	0–0.95

to be analytically tractable. Hence, we have to turn to results from simulations.

3.3 Simulation Results

Preference (β, ω) and structural (ζ, ρ) parameters influence the relative performance of monetary policy under discretion and the timeless-perspective rule. To evaluate each effect separately, we start from a benchmark model with parameter values presented in table 1 and then vary each parameter successively.

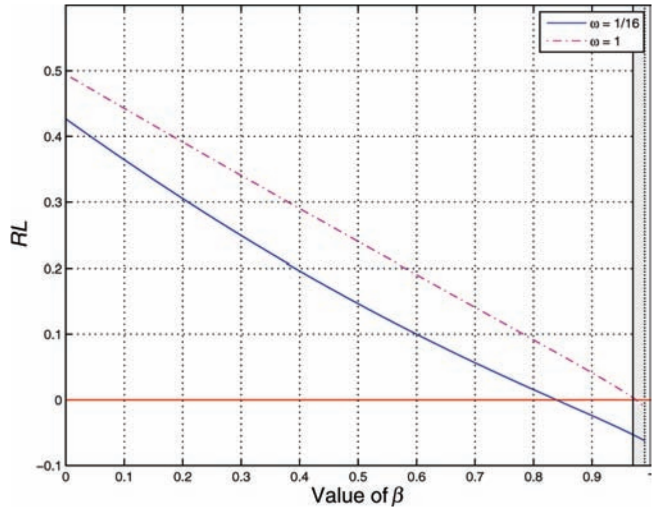
If one period in the model reflects one quarter, the discount factor of $\beta = 0.99$ corresponds to an annual real interest rate of 4 percent. Setting $\omega = 1/16$ implies an equal weight on the quarterly variances of annualized inflation and the output gap. For $\beta = 0.99$, $\zeta = 0.8722$ corresponds to $\alpha = 0.02$, the value used in Jensen and McCallum (2002) based on empirical estimates in Galí and Gertler (1999).[11]

To put the benchmark model into perspective, table 1 also reports the range of parameter values commonly used or estimated in the literature. For example, Ljungqvist and Sargent (2004) calibrate their model to β between 0.97 and 0.99.[12] Furthermore, Rudebusch and Svensson (1999) justify the use of unconditional expectations as their welfare criterion with the notion that conditional expectations of the total loss function (3), scaled by $(1 - \beta)$, and unconditional expectations of the period loss function, $E[L_t]$, converge for $\beta \rightarrow 1$

[11] ζ and α are linked through the definition of α in (2).

[12] Note that Galí, Gertler, and López-Salido (2001) estimate discount factors in the Phillips curve as low as 0.91 for the euro area and 0.92 for the United States. The implied steady-state real interest rate of approximately 12 percent per annum for $\beta = 0.97$ is, however, substantially above the empirically observed rate of about 2 percent per annum in developed economies.

Figure 1. Variation of Discount Factor β, TP vs. DIS



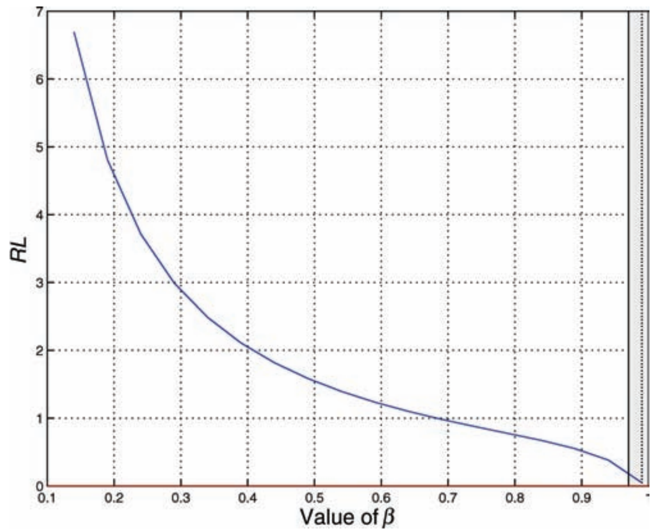
(see also Dennis 2004). Hence, values between 0.97 and 1 are used for β in the literature, while $\beta = 0.99$ represents the most common figure. The ranges for ω (0.01 to 0.25), α (0.01 to 0.1), and thus via (2) also ζ (0.73 to 0.91) are taken from the discussion of the literature in Walsh (2003, p. 527). Regarding the serial correlation of the cost-push shock, ρ, the literature covers a very broad range between 0 and 0.95 (see, e.g., Kuester, Müller, and Stölting 2007). Figures 1–5 in the remaining part of this section illustrate the parameter of the benchmark model as a dashed, vertical line and the range of parameters in the literature as a gray-shaded area.

3.3.1 Discount Factor β

Figure 1 presents the results for the variation of the discount factor β as the loss from the timeless perspective relative to discretionary policy, RL. A positive (negative) value of RL means that the loss from the timeless-perspective rule is greater (smaller) than the loss under discretion, while an increase (decrease) in RL implies a relative gain (loss) from discretion.

The simulation shows that RL increases with decreasing β; i.e., DIS gains relative to TP if the private sector puts less weight on the future. This pattern reflects proposition 2 in the previous section.

Figure 2. Variation of Discount Factor β Using Conditional Expectations of Loss Function, TP vs. DIS



Since the expectations channel becomes less relevant with smaller β, the stabilization bias and thus the long-run gains from commitment also decrease in β, whereas short-run losses remain unaffected.

In particular, DIS becomes superior to TP in the benchmark model for $\beta < 0.839$, but, e.g., with $\omega = 1$ already for $\beta < 0.975$.[13] Differentiating between the central bank's and the private sector's discount factor β (see McCallum 2005; Sauer 2007) shows that the latter drives RL because it enters the Phillips curve, while the former is irrelevant due to the use of unconditional expectations as the welfare criterion, as discussed in section 3.1. But since using the unconditional expectations of the loss function treats all periods the same and hence gives greater weight to future periods than actually valid for $\beta < 1$, this effect only strengthens the general argument.

This can be shown with the value of the loss function (3), $\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t L_t$, *conditional* on expectations at $t = 0$ instead of the *unconditional* expectations $E[L]$. As figure 2 demonstrates,

[13]The threshold of $\beta = 0.975$ for $\omega = 1$ is still a rather small value, as it implies a steady-state real interest rate of approximately 10 percent per annum.

the general impact of β on RL is similar to figure 1.[14] The notable difference is the absolute superiority of DIS over TP in our benchmark model, independently of β. In order to get a critical value of β for which DIS and TP produce equal losses, other parameters of the benchmark model have to be adjusted such that they favor TP, e.g., by reducing ω as explained below. Hence, figure 2 provides evidence that the use of unconditional expectations does not bias the results toward lower losses for discretionary policy. For reasons presented in section 3.1, we focus on unconditional expectations in this section.

3.3.2 Output-Gap Weight ω

In Barro and Gordon (1983b), the traditional inflation bias increases in the weight on the output gap, while the optimal stabilization policies are identical both under discretion and under commitment. In our intertemporal model without structural inefficiences, however, the optimal stabilization policies are different under DIS and COM/TP. The history dependence of TP in (10) improves the monetary authority's short-run output/inflation trade-off in each period because it makes today's output gap enter tomorrow's optimal policy with the opposite sign, but with the same weight ω/α in both periods. Hence, optimal current inflation depends on the *change* in the output gap under TP, but only on the contemporaneous output gap under DIS. This way, rule-based policymaking eliminates the stabilization bias and reduces the relative variance of inflation and output gap, which is a prominent result in the literature.[15]

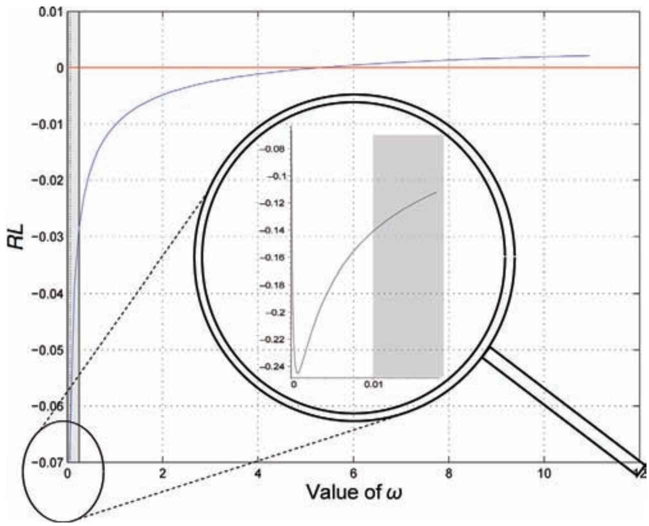
The short-run costs from TP arise because the monetary authority must be tough on inflation in the initial period. These short-run costs increase with the weight on the output gap ω.[16] The long-run gains from TP are caused by the size of the stabilization bias and the importance of its elimination given by the preferences in the loss function. Equation (10) shows that increasing ω implies a softer policy on inflation today but is followed by a tougher policy tomorrow. Although the effect of tomorrow's policy is discounted by the private sector with β, the size of the stabilization bias—i.e., the neglection of

[14]The use of conditional expectations requires setting the initial conditions—i.e., y_{-1} and u_0—to specific values. In figure 2, $y_{-1} = -0.02$ and $u_0 = 0$.

[15]See, e.g., Dennis and Söderström (2006) and Woodford (1999).

[16]The optimal output gap y_t under DIS is decreasing in ω; see equation (6).

Figure 3. Variation of Weight on the Output Gap ω, TP vs. DIS



the possibility to spread shocks over several periods—appears to be largely independent from ω. However, the reduction in the relative variance of inflation due to TP becomes less important the larger the weight on the variance of the output gap in the loss function—i.e., the long-run gains from TP decrease in ω.

In the benchmark model of figure 3, RL initially decreases from 0 for $\omega = 0$ with increasing ω.[17] But for reasonable values of ω—i.e., $\omega > 0.0009$ in the benchmark model—RL increases in the preference for output stabilization since short-run costs increase and long-run gains decrease in the weight on the output gap (increasing ω). DIS even outperforms TP for $\omega > 5.28$, which is an extraordinarily large value empirically, however.[18]

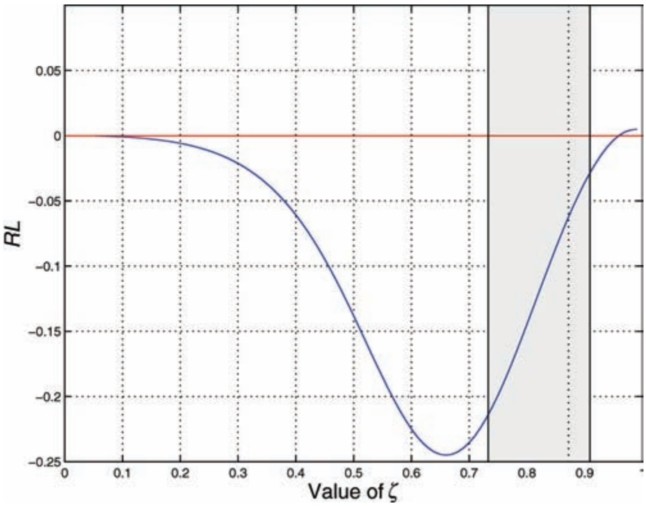
3.3.3 Price Rigidity ζ

Proposition 1 states that DIS and TP are equivalent for perfectly flexible prices; i.e., $\zeta = 0$ or $\alpha \to \infty$, respectively. Increasing price

[17]Note the magnifying glass in figure 3.

[18]RL may approach 0 again for $\omega \to \infty$, the (unreasonable) case of an "employment nutter."

Figure 4. Variation of Degree of Price Rigidity ζ, TP vs. DIS

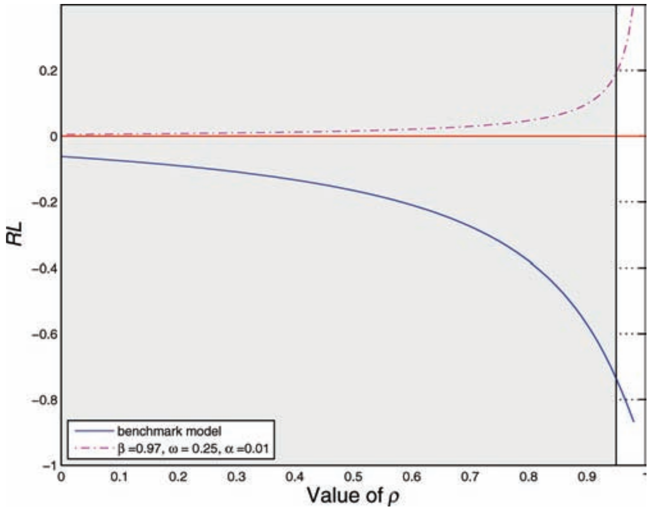


rigidity—i.e., increasing ζ—has two effects: First, firms' price setting becomes more forward looking because they have fewer opportunities to adjust their prices. This effect favors TP over DIS for increasing ζ because TP optimally incorporates forward-looking expectations. Second, more rigid prices imply a flatter Phillips curve, and thus the requirement of TP to be tough on inflation already in the initial period becomes more costly. Hence, the left-hand side of (11), the short-run losses from TP over DIS, increases. Figure 4 demonstrates that for $\zeta > 0.660$, the second effect becomes more important and for $\zeta > 0.959$, the second effect even dominates the first one.[19]

Based on the discussion of the literature in Walsh (2003), common estimates for price rigidity lie within $\alpha \in [0.01; 0.10]$; i.e., $\zeta \in [0.909; 0.733]$. In this range, figure 4 shows that RL increases with the firms' probability of not being able to reset their price, ζ, and exceeds 0 for $\zeta > 0.959$ or $\alpha < 0.002$.

[19]Since the relationship between ζ and α given by equation (2) also depends on β, there is a qualitatively irrelevant and quantitatively negligible difference between varying the probability of no change in a firm's price, ζ, and directly varying the output-gap coefficient in the Phillips curve, α.

Figure 5. Variation of Degree of Serial Correlation ρ, TP vs. DIS



3.3.4 Correlation of Shocks ρ

The analysis of the influence of serial correlation in cost-push shocks, ρ, is more complex. L_{DIS} exceeds L_{TP} in the benchmark model with $\rho = 0$, and raising ρ ceteris paribus strengthens the advantage of TP as demonstrated in the solid line in figure 5. If shocks become more persistent, their impact on future outcomes increases, and thus TP gains relative to DIS because it accounts for these effects in a superior way. The long-run gains from TP dominate its short-run losses, and RL decreases with ρ.

However, the relationship between ρ and RL is not independent of the other parameters in the model, while the relationships between RL and β, ζ, and ω, respectively, appear to be robust to alternative specifications of other parameters. Broadly speaking, as long as $L_{DIS} > L_{TP}$ for $\rho = 0$, varying ρ results in a diagram similar to the solid line in figure 5; i.e., $L_{DIS} > L_{TP}$ for all $\rho \in [0; 1)$, and RL decreases in ρ.

On the contrary, an appropriate combination of β, ζ, and ω can lead to $L_{DIS} \leq L_{TP}$ for $\rho = 0$. For example, the combination of a low discount factor with rigid prices and a high preference for output-gap stabilization—such as the values $\beta = 0.97, \zeta = 0.91$, and $\omega = 0.25$ reported from the literature in table 1—results in $RL > 0$.

In this case, a picture symmetric to the horizontal axis emerges, as shown by the dashed line in figure 5.[20] That means that a higher degree of serial correlation only strengthens the dominance of either TP or DIS already present without serial correlation. Hence, serial correlation on its own does not seem to be able to overcome the result of the trade-off between short-run losses and long-run gains from TP implied by the other parameter values.[21]

3.4 Effects of Initial Conditions

As argued in section 3.1, we have to use conditional expectations of $\mathcal{L}$ in (3) in order to investigate the effects of the initial conditions—i.e., the previous output gap y_{-1} and the current cost-push shock u_0—on the relative performance of policy rules. Figure 6 presents the relative loss $\widehat{RL} = \mathcal{L}_{TP}/\mathcal{L}_{DIS} - 1$ conditional on y_{-1} and u_0 in the range between –0.05 and 0.05 from different viewpoints.[22]

Starting from the steady state with $y_{-1} = u_0 = 0$ where $\widehat{RL} = -0.0666$ in the benchmark model, increasing the absolute value of the initial lagged output gap $|y_{-1}|$ increases the short-run cost from following TP instead of DIS and leaves long-run gains unaffected: While $\pi_{0,DIS} = y_{0,DIS} = 0$ from (12) and (13), $\pi_{0,TP}$ and $y_{0,TP}$ deviate from their target values as can be seen from the history dependence of (10) or the MSV solution (16) and (17). Hence, TP becomes suboptimal under conditional expectations for sufficiently large $|y_{-1}|$. Note also that this short-run cost is symmetric to the steady-state value $y_{-1} = 0$ (see figures 6A and 6B).

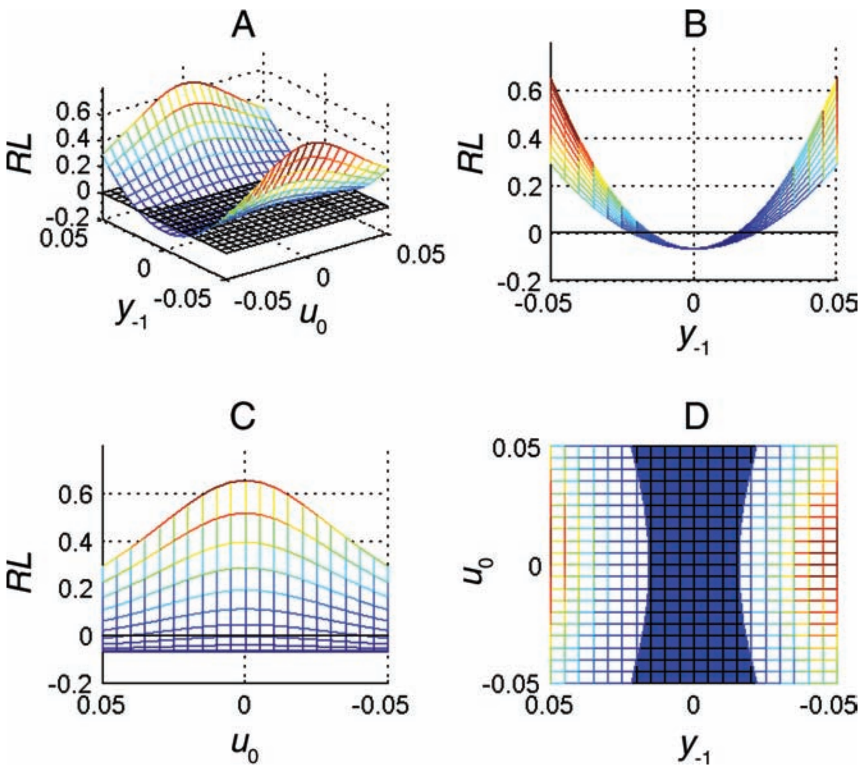
If in addition to $|y_{-1}| > 0$ a cost-push shock $|u_0| > 0$ hits the economy, the absolute losses under both DIS and TP increase. Since TP allows an optimal combination of the short-run cost from TP, the inclusion of $|y_{-1}| > 0$ in (10), with the possibility to spread the

[20]For parameter combinations that result in L_{DIS} in the neighborhood of L_{TP} for $\rho = 0$, increasing ρ has hardly any influence on RL, but for high degrees of serial correlation from about $\rho > 0.8$, RL increases rapidly.

[21]This shows that the results in McCallum and Nelson (2004, p. 48), who only report the relationship visible from the solid line in figure 5, do not hold in general.

[22]Figure 6A offers the complete three-dimensional perspective of $\widehat{RL}$ with an additional plane marking $\widehat{RL} = 0$; figure 6B turns to the $y_{-1} - \widehat{RL}$ perspective and figure 6C to the $u_0 - \widehat{RL}$ perspective; figure 6D provides the birds-eye view, with the shaded area signaling $\widehat{RL} < 0$.

Figure 6. $\widehat{RL}$ Depending on y_{-1} and u_0



impact of the initial shock $|u_0| > 0$ over several periods, a larger shock u_0 alleviates the short-run cost from TP. Hence, the relative loss $\widehat{RL}$ from TP decreases in $|u_0|$ for any given $|y_{-1}| > 0$ (see figures 6A and 6C).

However, this effect is weaker the closer $|y_{-1}|$ is to 0, as can be seen from the lines in figure 6C: the smaller $\widehat{RL}$ is at $u_0 = 0$ because of a smaller given $|y_{-1}|$, the less bent is the respective line depicting $\widehat{RL}$. If $y_{-1} = 0$, the size of $|u_0|$ has no influence on $\widehat{RL}$ anymore since DIS and TP do not differ in $t = 0$.[23] In this case, $\widehat{RL}$ is parallel

[23]To be precise, the policy "rules" (6) and (10) do not differ in $t = 0$, but the losses differ because of the more favorable output/inflation trade-off through the impact of TP on $E_0\pi_1$ in (1). This benefit of TP is part of the long-run gains, however, because it is also present under COM.

to the u_0-axis. While u_0 still influences the *absolute* loss values $\mathcal{L}$ under both policies and how these losses are spread over time under TP, it has no influence on the *relative* gain from TP as measured by $\widehat{RL}$, which is solely determined by the long-run gains from TP for $y_{-1} = 0$.

The shaded area in figure 6D summarizes the previous information, as it illustrates all combinations of u_0 and y_{-1} for which $\widehat{RL} < 0$. DIS is superior to TP for all other combinations of u_0 and y_{-1}.

Note that $\widehat{RL}$ is symmetric both to $y_{-1} = 0$ for any given u_0 and to $u_0 = 0$ for any given y_{-1}. Under DIS, y_{-1} has no impact because (6) is not history dependent and u_0 only influences the respective period loss L_0, which is the weighted sum of the *variances* π_0^2 and y_0^2. Hence, $\mathcal{L}_{DIS}$ is independent of y_{-1} and symmetric to $u_0 = 0$.

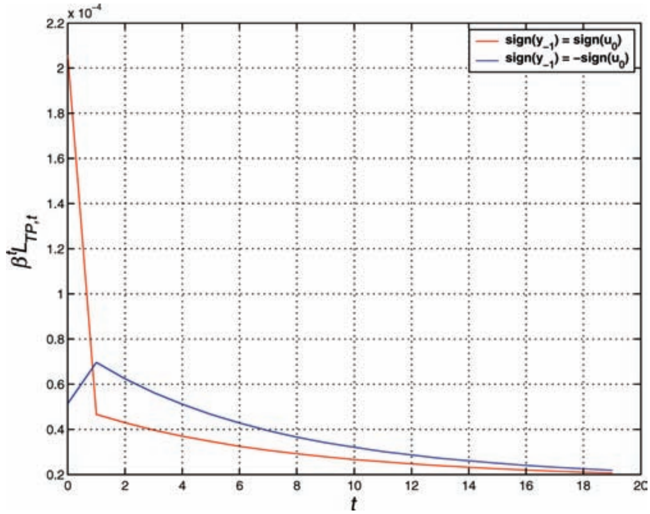
Under TP, however, the history dependence of (9) makes y_{-1} and u_0 influence current and future losses. While the transitional dynamics differ with the relative sign of u_0 and y_{-1}, the total absolute loss $\mathcal{L}_{TP}$ does not for any given combination of $|y_{-1}|$ and $|u_0|$. If the economy was in a recession ($y_{-1} < 0$) in the previous period, for example,[24] the price to pay under TP is to decrease π_0 through dampening y_0 with a ceteris paribus restrictive monetary policy that lowers aggregate demand.

Scenario 1. If additionally a negative cost-push shock $u_0 < 0$ hits the economy—i.e., with the *same* sign as $y_{-1} < 0$—this shock lowers π_0 further as the Phillips curve (1) is shifted downward from its steady-state locus. At the same time, $u_0 < 0$ increases y_0 ceteris paribus,[25] brings y_0 closer to the target of 0, and thus reduces the price to pay for TP in the next periods $t = 1, \ldots$. The anticipation of this policy in turn lowers inflation expectations $E_0\pi_1$ compared with the steady state. Therefore, the Phillips curve shifts even further down and the output gap y_0 closes even more in the resulting equilibrium.

[24] The following arguments run in a completely analogous manner for $y_{-1} > 0$ (see Sauer 2010).

[25] Formally, partial derivatives of (16) and (17) with respect to both state variables (y_{t-1}, u_t) show that both have the same qualitative effect on π_t and an opposing effect on y_t: $\partial\pi_t/\partial y_{t-1} = \frac{\omega(1-\delta)}{\alpha} > 0$ and $\partial\pi_t/\partial u_t = \frac{1}{\gamma-\beta(\rho+\delta)} > 0$ while $\partial y_t/\partial y_{t-1} = \delta > 0$ and $\partial y_t/\partial u_t = \frac{-\alpha}{\omega(\gamma-\beta(\rho+\delta))} < 0$.

Figure 7. Discounted Per-Period Loss Values $L_{TP,t}$ for $|y_{-1}|$ and $|u_0|$



Scenario 2. If, however, the initial cost-push shock u_0 is positive—i.e., of *opposite* sign to $y_{-1} < 0$—the transitional dynamics are reversed. The Phillips curve (1) is shifted upward. In contrast to scenario 1 with $u_0 < 0$, this reduces the negative impact of y_{-1} on π_0 but increases y_0. Hence, the price to pay under TP in $t = 1$ is larger than in scenario 1, which in turn also lowers inflation expectations $E_0\pi_1$ by more. The additional shift of the Phillips curve downward is thus larger than for $u_0 < 0$.

Figure 7 presents the discounted period losses under TP for both cases in the benchmark model. The behavior of the economy as described above causes a larger loss in the initial period for the first scenario with $\text{sign}(y_{-1}) = \text{sign}(u_0)$ compared with the case with $\text{sign}(y_{-1}) = -\text{sign}(u_0)$ because the expectations channel has a smaller impact; but it causes a reversal of the magnitude of losses for $t \geq 1$ because the price to pay for TP then is larger until the period loss converges to its unconditional value. Since the sum of the discounted losses, however, is equal in both scenarios, $\mathcal{L}_{TP}$ is symmetric to $u_0 = 0$ given y_{-1} and to $y_{-1} = 0$ given u_0.

To summarize, figure 6 presents the influences of the initial conditions on the relative performance of TP and DIS and the rest of this section provides intuitive explanations of the effects present in the model. $\widehat{RL}$ becomes positive—i.e., DIS performs better than TP—in the benchmark model for quite realistic values of the initial conditions, e.g., $\widehat{RL} > 0$ for $|y_{-1}| = 0.015$ and $|u_0| = 0.01$. Hence, it may not be welfare increasing for an economy to switch from DIS to TP if it is not close to its steady state.

The previous sections 3.2 and 3.3 demonstrated, based on unconditional expectations as welfare criterion, the possibility that DIS outperforms TP for some rather extreme combinations of parameters. This section has highlighted three points: First, the use of conditional expectations as a welfare criterion may have important consequences for the evaluation of different policies (see also Kim et al. 2008; Schmitt-Grohé and Uribe 2004, for example). Second, the relevance of the results presented in this paper may be non-negligible in practice given that already small deviations from the steady state suffice to make discretion superior to the timeless-perspective rule. Third, other papers have shown that a timeless-perspective rule exists that is optimal for all combinations of parameters under unconditional expectations as welfare criterion (Blake 2001; Damjanovic, Damjanovic, and Nolan 2008; Jensen and McCallum 2002; Sauer 2007). However, this rule results in a diagram that is similar to figure 6 when its performance is evaluated for different initial conditions under conditional expectations (see Sauer 2007). For *any* timeless rule, initial conditions and hence the short-run costs can be sufficiently adverse to make the rule inferior to discretion.

4. Conclusion

This paper explores the theoretical implications of the timeless-perspective policy rule and discretionary policy under varying parameters in the New Keynesian model. With the comparison of short-run gains from discretion over rule-based policy and long-run losses from discretion, we have provided a framework in which to think about the impact of different parameters on monetary policy rules versus discretion. This framework allows intuitive economic explanations of the effects at work.

Already Blake (2001), Jensen (2003), and Jensen and McCallum (2002) provide evidence that a policy rule following the timeless perspective can cause larger losses than purely discretionary modes of monetary policymaking in special circumstances. But none of these contributions considers an economic explanation for this rather unfamiliar result, let alone analyzes the relevant parameters as rigorously as this paper.

What recommendations for economic policymaking can be derived? Most importantly, the timeless perspective in its standard formulation is not optimal for all economies at all times. Considering each parameter separately, the critical values obtained in this paper require a lower discount factor, a greater degree of price rigidity, or a higher preference for output stabilization than calibrated or estimated in most of the literature. But if an economy features a combination of these characteristics and in particular a sufficiently large deviation from its steady state, the long-run losses from discretion may be less relevant than previously thought. In this case, discretionary monetary policy appears preferable over the timeless perspective.

In an overall laudatory review of Woodford (2003), Walsh (2005) argues that Woodford's book "will be widely recognized as the definitive treatise on the new Keynesian approach to monetary policy." He criticizes the book, however, for its lack of an analysis of the potential short-run costs of adopting the timeless-perspective rule. Walsh (2005) sees these short-run costs arising from incomplete credibility of the central bank. Our analysis has completely abstracted from such credibility effects and still found potentially significant short-run costs from the timeless perspective. Obviously, if the private sector does not fully believe in the monetary authority's commitment, the losses from sticking to a rule relative to discretionary policy are even greater than in the model used in this paper. One way to incorporate such issues is to assume that the private sector has to learn the monetary policy rule. Evans and Honkapohja (2001) provide a convenient framework to analyze this question in more detail.

Appendix. Derivation of L_{TP}

The unconditional loss for the timeless perspective, equation (21), can be derived in several steps. The MSV solution (16) and (17) depends on two state variables, y_{t-1} and u_t. From the conjectured solution in (15), we have

$$E\left[y_t^2\right] = \phi_{21}^2 E\left[y_{t-1}^2\right] + \phi_{22}^2 E\left[u_t^2\right] + 2\phi_{21}\phi_{22}E[y_{t-1}u_t]. \tag{23}$$

$E[y_{t-1}u_t]$ can be calculated from (15) with $u_t = \rho u_{t-1} + \epsilon$ as

$$\begin{aligned} E[y_{t-1}u_t] &= E[(\phi_{21}y_{t-2} + \phi_{22}(\rho u_{t-2} + \epsilon_{t-1}))(\rho u_{t-1} + \epsilon_t)] \\ &= E\left[\phi_{21}\rho \underbrace{y_{t-2}u_{t-1}}_{=E[y_{t-1}u_t]} + \phi_{22}\left(\rho^2 \underbrace{u_{t-1}u_{t-2}}_{=\rho\sigma_u^2} + \rho \underbrace{u_{t-1}\epsilon_{t-1}}_{=\sigma^2}\right)\right] + 3 \cdot 0, \end{aligned} \tag{24}$$

since the white-noise shock ϵ_t is uncorrelated with anything from the past. Solving for $E[y_{t-1}u_t]$ with $\sigma_u^2 = \frac{1}{1-\rho^2}\,\sigma^2$ gives

$$E[y_{t-1}u_t] = \frac{\phi_{22}\rho}{1-\phi_{21}\rho} \cdot \frac{1}{1-\rho^2}\,\sigma^2. \tag{25}$$

Plugging this into (23), using $E[y_t^2] = E[y_{t-1}^2] = E[y^2]$ and ϕ_{21}, ϕ_{22} from the MSV solution (17) leaves

$$\begin{aligned} E[y^2] &= \frac{1}{1-\phi_{21}^2}\left(\phi_{22}^2 + \frac{2\phi_{21}\phi_{22}^2\rho}{1-\phi_{21}\rho}\right)\frac{1}{1-\rho^2}\,\sigma^2 \\ &= \frac{\alpha^2(1+\delta\rho)}{\omega^2(1-\delta^2)(1-\delta\rho)[\gamma-\beta(\delta+\rho)]^2} \cdot \frac{1}{1-\rho^2}\,\sigma^2. \end{aligned} \tag{26}$$

From the conjectured solution in (14), we have

$$E\left[\pi_t^2\right] = \phi_{11}^2 E\left[y_{t-1}^2\right] + \phi_{12}^2 E\left[u_t^2\right] + 2\phi_{11}\phi_{12}E[y_{t-1}u_t]. \tag{27}$$

Combining this with the previous results and the MSV solution (16) results in

$$E[\pi^2] = \frac{2(1-\rho)}{(1+\delta)(1-\delta\rho)[\gamma-\beta(\delta+\rho)]^2} \cdot \frac{1}{1-\rho^2}\,\sigma^2. \tag{28}$$

Hence, L_{TP} as the weighted sum of $E[\pi^2]$ and $E[y^2]$ is given by

$$L_{TP} = \frac{2\omega(1-\delta)(1-\rho) + \alpha^2(1+\delta\rho)}{\omega(1-\delta^2)(1-\delta\rho)[\gamma-\beta(\delta+\rho)]^2} \cdot \frac{1}{1-\rho^2}\,\sigma^2. \tag{29}$$

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Optimal Monetary Policy in Response to Cost-Push Shocks: The Impact of Central Bank Communication*

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This paper argues that a central bank's optimal policy in response to a cost-push shock depends upon its disclosure regime. More precisely, a credible central bank may find it optimal to implement an accommodative monetary policy in response to a positive cost-push shock whenever the uncertainty surrounding its monetary instrument is high. Indeed, the degree of the central bank's transparency influences the effectiveness of its policy to stabilize inflation in terms of output gap. The effectiveness, in turn, determines whether it will implement an expansionary or contractionary policy in response to a positive cost-push shock.

JEL Codes: E58, E52, D82.

1. Introduction

How should a central bank respond to a cost-push shock? Since cost-push shocks simultaneously create both an upsurge in inflation

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and a negative output gap, the optimal central bank response is highly controversial. The very nature of a cost-push shock gives rise to a dilemma for the central bank. The bank can either ease its monetary policy to accommodate the negative output gap or tighten it to fight the upsurge in inflation. Under what conditions will a central bank decide to pursue the first strategy rather than the second? This paper aims to show that the optimal response to a cost-push shock is driven by the communication regime followed by the central bank.

During the 1970s, as the price for oil rose dramatically, many countries experienced large positive cost-push shocks. In an empirical analysis, Clarida, Galí, and Gertler (2000) show that the Federal Reserve eased its monetary policy in response to these oil shocks. Indeed, they argue (p. 168) that "it is hard to imagine . . . that the 1973 oil shock alone could have generated high inflation . . . in the absence of an accommodating monetary policy." While these authors show that monetary policy was accommodative in the pre-Volcker era and restrictive during the Volcker-Greenspan era, their paper does not provide any rationale for such a change. More generally, it remains unclear why monetary policy apparently accommodated the large positive cost-push shocks in the 1970s but not in the 1990s.

Over the last decades, there has been a switch in central banks' communication strategy: from secrecy toward greater transparency.[1] We show that such a change in transparency has strong implications for how to optimally deal with a cost-push shock: the optimal policy a central bank should adopt in response to a cost-push shock depends upon its disclosure regime. De Long (1997) largely documents the evolution in the perception of the response to be adopted in the event of a cost-push shock. He underlines central bankers' concern for the impact of a restrictive monetary policy on output and, more particularly, on unemployment. Our model shows that the trade-off between inflation and output strongly depends on the level of transparency in the economy. In the case of opacity, the trade-off does not promote inflation stabilization. Given opaque communication, the

[1] An emblematic example is the publication of the monetary instrument by the Federal Reserve from 1994 on. The increase in transparency in the conduct of monetary policy in recent years is studied by Dincer and Eichengreen (2006) and Eijffinger and Geraats (2006).

central bank can only reduce inflation at the cost of a strong decrease in output. Increasing the central bank's transparency reduces the cost of stabilizing inflation. De Long argues that the main reason for the inflation in the '70s lies in the "shadow of the Great Depression." Our model suggests that the central banks in the '70s had good reasons to fear recession (De Long 1997) or to emphasize output-gap stabilization (Orphanides 2005). The opacity characterizing policy at that time would have caused strong contractions in output.

We propose a monetary policy model under monopolistic competition with heterogeneous information on the cost-push shocks affecting the economy. We base our analysis on the literature in the vein of Adam (2007), Hellwig (2002), Morris and Shin (2002), and Woodford (2003) who—among others—recently emphasized that, in an economy characterized by strategic complementarities, heterogeneous information can lead to realistic dynamics of transmission mechanisms.[2] Our approach is unique in that we analyze the role of the central bank's communication regime for the conduct of monetary policy under the imperfect-information hypothesis. We consider a central bank that has no inflationary bias and whose preferences are perfectly known by the private sector.[3] Both the central bank and firms are uncertain about the true state of the economy and receive private signals on cost-push shocks. We assume that the communication regime of the central bank is exogenous and defined as follows. The central bank can be transparent, disclosing all the information it has about the macroeconomic conditions. Or it can be opaque, in the sense that it does not disclose any information about macroeconomic conditions. We can also distinguish any intermediate situation in which the central bank discloses information about macroeconomic conditions in a more or less ambiguous manner.[4] Firms receive a signal on the monetary instrument of the central bank according to the degree of transparency of the central bank

[2]See also Mankiw and Reis (2002).

[3]We concentrate on well-established and credible central banks, i.e., without inflationary bias. This is natural in the current context of central bank independence and historically—and durable—low levels of inflation of most OECD countries.

[4]The notion of transparency considered in this paper is therefore economic transparency according to the classification of Geraats (2002).

with respect to its policy. While the central bank's disclosure does not contain any valuable information under opacity, the monetary instrument is common knowledge among firms under transparency. Taking into account the potentially informative role of the monetary instrument[5] is in line with empirical evidence.[6] We derive the optimal monetary policy depending on the communication regime of the central bank (opacity vs. transparency cases and any intermediate situation) when imperfect information is responsible for money non-neutrality.

The model is as follows. In an economy where firms' prices are strategic complements, the effectiveness of monetary policy on the pricing rule of firms is driven by the disclosure of the central bank, since it determines the fundamental and strategic uncertainty surrounding its monetary instrument. The information disclosed by the central bank influences the reaction of the price level to monetary policy and thus influences the extent to which the central bank can deal with the trade-off generated by cost-push shocks. Under transparency, as the monetary instrument is common knowledge among firms, optimal monetary policy always contracts the nominal demand. In contrast, opacity increases fundamental and strategic uncertainty about the central bank's action, thereby reducing the effectiveness of monetary policy on the price level. Contracting the nominal demand is ineffective for reducing the price level. The central bank may find it optimal to reduce the output gap by expanding its instrument.[7] However, opacity is not a sufficient condition for the optimal monetary policy to be accommodative. The sign of the policy coefficient depends on the relationship between the degree of

[5]Here our work relates to Baeriswyl and Cornand (2006) and Walsh (2006, 2007), who consider that the monetary instrument is both an action and a vehicle for information.

[6]In an empirical analysis of U.S. data, Romer and Romer (2000) show that the observation of the monetary instrument highly influences the formation of market expectations. Moreover, Demiralp and Jordà (2002) emphasize the relevance of central bank communication to manipulate market expectations. They show, in particular, that the publication of the instrument rate targeted by the policy board of the Federal Reserve since 1994 has increased the effectiveness of monetary policy to shape market expectations (via an announcement effect).

[7]While Goodfriend and King (2005) argue that the lack of a central bank's credibility increases the cost of disinflation, our analysis emphasizes the role of a central bank's transparency as a determinant of the costs of inflation stabilization.

strategic complementarities, the preference of the central bank for output-gap stabilization, and the relative precision of firms' private information.

The remainder of this paper is structured as follows. Section 2 outlines a monopolistic-competition economy, in which firms' pricing decisions represent strategic complements. Section 3 considers a benchmark case under common information and develops intuition for our main result. Section 4 examines the case of heterogeneous information and shows that the optimal monetary policy under opacity may be to accommodate a cost-push shock. We also show that small changes in the degree of transparency or in preferences may have large effects on the optimal monetary policy. Finally, section 5 concludes.

2. The Economy

The model is derived from an economy with flexible prices, populated by a continuum of monopolistic competitive firms and a central bank. The economy is affected by stochastic cost-push shocks that are normally distributed:

$$u \sim N\big(0, \sigma_u^2\big).$$

Nominal aggregate demand is determined by the monetary instrument I set by the central bank.

2.1 Firms

The behavior of firms consists in choosing a price. Under monopolistic competition à la Dixit-Stiglitz, firms set their price as a function of their expectations of the overall price level p, the real output gap y, and the cost-push shock u.[8] One can show that the optimal price of firm i is given by

$$p_i = \mathbb{E}_i[p + \xi y + u], \tag{1}$$

where variables are expressed as percentage deviations from the deterministic steady state. The pricing rule (1) captures the strategic complementarities in prices. Indeed, each firm i sets its price

[8]For the microfounded derivation, see Adam (2007) or Woodford (2003).

according to its expectation about both fundamentals (the output gap y and the cost-push shock u) and the average action of others, the overall price level p.

The parameter ξ determines to what extent the optimal price responds to the output gap. As we assume below, the central bank determines the nominal aggregate demand through its monetary instrument I. Using the fact that the nominal aggregate demand I is by definition equal to $y + p$, we rewrite the pricing rule (1) as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi I + u]. \tag{2}$$

In the whole paper, we realistically assume that prices are strategic complements and impose $0 < \xi \leq 1$. When ξ decreases, the optimal price setting responds less strongly to fundamentals (I and u) and more strongly to the strategic term, the overall price level p: the degree of strategic complementarities increases.

While prices are flexible in our model, heterogeneous information among firms may account for non-neutral effects of monetary policy. Indeed, Hellwig (2002) or Woodford (2003) show that the lack of information about each other's expectations (higher-order uncertainty) yields nominal adjustment delays of prices.

2.2 Central Bank

Following much of the literature, we assume that the central bank minimizes the deviation of both the output gap y and the price level p from their respective target owing to its monetary instrument I. The central bank's optimization problem corresponding to flexible inflation targeting can be described by its loss,

$$L = \min_I \mathbb{E}_{cb}[\lambda y^2 + p^2], \tag{3}$$

where λ is the weight assigned to the output-gap variability.

Note that the central bank has no incentive to push the output above its natural level. For the sake of simplicity, as mentioned above, we assume that the central bank directly controls the nominal aggregate demand with its monetary instrument I.

3. Common Information

Standard monetary policy analysis assumes that information is common knowledge among firms. While this paper deals with monetary policy under heterogeneous information, the current section derives, as a benchmark, the optimal monetary policy under common knowledge.

When information is perfect and common to all firms, each firm sets the same price ($p_i = p$). The pricing rule (2) then simplifies to

$$p_i = p = I + \frac{1}{\xi}u.$$

The impact of cost-push shocks u on the price level increases with the degree of strategic complementarities $1-\xi$. When ξ is small, nominal aggregate demand is given a lower weight in the pricing rule, which increases the relative weight assigned to cost-push shocks.

The central bank chooses its instrument to minimize its loss (3) based on its signal on the cost-push shock: $u_{cb} = u + \mu$, with $\mu \sim N(0, \sigma_\mu^2)$. The monetary instrument is linear in central bank's signal u_{cb}: $I = \nu u_{cb}$, where ν stands for the monetary policy coefficient. When the central bank has perfect information about the shock, its monetary instrument simplifies to $I = \nu u$.

The loss under perfect information can be written as

$$L = \lambda \left(-\frac{1}{\xi}u\right)^2 + \left[\left(\frac{1}{\xi} + \nu\right) u\right]^2,$$

and minimizing it yields the following optimal monetary policy:

$$\nu = -\frac{1}{\xi}. \tag{4}$$

The corresponding unconditional expected loss is a function of the variance of cost-push shocks:

$$\mathbb{E}(L) = \frac{\lambda}{\xi^2}\sigma_u^2.$$

The optimal monetary policy coefficient ν states that the central bank contracts nominal aggregate demand by $-\frac{1}{\xi}$ when the cost-push shock increases by one unit. Contracting aggregate demand whenever cost-push shocks are positive is known as *leaning against the wind*.[9] As the price level increases in the case of a positive cost-push shock, the central bank contracts the nominal aggregate demand to stabilize it. The strength of the central bank's response increases with the degree of strategic complementarities.

The optimal monetary policy derived in this section illustrates that under common information, the central bank finds it optimal to stabilize the price level. By contrast, as we shall see in the next section, when the monetary instrument is not common knowledge among firms, optimal monetary policy may call for output-gap stabilization.

4. Heterogeneous Information

We now turn to the more realistic case where firms have heterogeneous information about the state of the economy. We apply the methodology of Morris and Shin (2002) to our optimal monetary policy framework. These authors emphasize the relevance of public information in an economy characterized by strategic complementarities and heterogeneous information.

4.1 Information Structure

The information structure in the economy is as follows. Let's recall that the central bank receives a private signal on the cost-push shock that deviates from the true fundamental value by an error term that is normally distributed:

$$u_{cb} = u + \mu, \text{ with } \mu \sim N\big(0, \sigma_\mu^2\big).$$

[9] There is wide agreement among economists that a good monetary policy typically calls for leaning against the wind. The general idea is to keep inflation under control by contracting the economy or equivalently taking a restrictive action whenever inflation is above target. Note that some authors adopt other definitions for this expression. For instance, Schwartz (2003, p. 1025) argues that "the Fed should 'lean against the wind,' by taking restrictive action during periods of economic expansion and expansionary action during periods of economic contraction." By contrast, Clarida, Galí, and Gertler (1999, p. 1672) say that "the central bank pursues a 'lean against the wind' policy: Whenever inflation is above target, contract demand below capacity (by raising the interest rate)."

The central bank chooses its instrument to minimize (3). The optimal instrument rule of the central bank is a linear function of its signal and can be written as

$$I = \nu(u + \mu). \tag{5}$$

Each firm i receives a private signal on the cost-push shock u_i. The private signal of each firm deviates from the true cost-push shock by an error term that is normally distributed:

$$u_i = u + \rho_i, \text{ with } \rho_i \sim N\big(0, \sigma_\rho^2\big),$$

where ρ_i are identically and independently distributed across firms.

In addition to their private signal about the cost-push shock, firms get a signal on the monetary instrument.[10] The information conveyed by the central bank's disclosure depends upon its degree of transparency with respect to its monetary instrument. Each firm i receives a signal on the central bank assessment about the state of the economy that is written, for the sake of generality, as

$$D_i = D + \phi_i = u + \mu + \phi_i, \text{ with } \phi_i \sim N\big(0, \sigma_\phi^2\big),$$

where σ_ϕ^2 captures the uncertainty surrounding the monetary instrument in the economy. We assume that the communication regime (or degree of transparency of the central bank) is exogenous.[11] Since firms are rational, they know the policy coefficient ν and can infer the instrument implemented by the central bank from their signal on its economic assessment. When the central bank is transparent, all firms perfectly infer the true instrument (i.e., $\sigma_\phi^2 \to 0$) and it becomes common knowledge among them. By contrast, under opacity (i.e., $\sigma_\phi^2 \to \infty$), the central bank's disclosure does not contain any valuable information. This increases the uncertainty of firms about the instrument.

[10] This feature is empirically well documented by Romer and Romer (2000).

[11] A normative analysis of welfare goes beyond the scope of this paper. This paper simply aims at showing that the optimal response to cost-push shocks depends upon the disclosure regime of the central bank. When the central bank directly discloses its economic assessment, the signaling role of its monetary instrument becomes redundant, which allows to abstract from considering strategic distortions of the instrument.

Historically, central banks used to be extremely opaque and recently have become more and more transparent about their instrument. For example, before February 1994, the Federal Reserve did not publicly report on the federal funds rate it was targeting. In this context, the private sector had to infer the policy decisions of the Federal Open Market Committee from the market operations conducted by the trading desk of the Federal Reserve. This lack of transparency was a source of fundamental uncertainty about the rate targeted by the Federal Reserve and of strategic uncertainty about the beliefs of others about this target.

4.2 Equilibrium

To determine the perfect Bayesian equilibrium behavior of firms, we recall the optimal pricing rule (2) for convenience and substitute successively the average price level with higher-order expectations about the cost-push shock and the monetary instrument:

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + u + \xi I] \\ &= \mathbb{E}_i\left[u + \xi I + (1-\xi)\left[\bar{\mathbb{E}}\left[u + \xi I + (1-\xi)\left[\bar{\mathbb{E}}[u + \xi I + \ldots]\right]\right]\right]\right]. \end{aligned}$$

We denote by $E_i(.)$ the expectation operator of firm i conditional on its information and by $\bar{\mathbb{E}}(.)$ the average expectation operator such that $\bar{\mathbb{E}}(.) = \int_i E_i(.)di$. With heterogeneous information, the law of iterated expectations fails since expectations of higher order do not collapse to the average expectation of degree one.[12] Thus, we rewrite the pricing rule as

$$p_i = \sum_{k=0}^{\infty}(1-\xi)^k \mathbb{E}_i[\bar{\mathbb{E}}^{(k)}(u + \xi I)],$$

and averaging over firms yields

$$p = \sum_{k=0}^{\infty}(1-\xi)^k [\bar{\mathbb{E}}^{(k+1)}(u + \xi I)], \tag{6}$$

[12] See Morris and Shin (2002).

where $\bar{\mathbb{E}}^{(k)}$ stands for the higher-order expectation of degree k. We use the following notation of higher-order expectations: $\bar{\mathbb{E}}^{(0)}(x) = x$ is the expected variable x itself, $\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}(x)$ is the average expectation of x, $\bar{\mathbb{E}}^{(2)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}(x)$ is the average expectation of the average expectation of x, and so on.

In order to solve the inference problem of each firm

$$\mathbb{E}_i(u, I) = \mathbb{E}[u, I|u_i, D_i],$$

we define from the formula for conditional expectations of jointly normal random variables the corresponding covariance matrix $\mathbf{V}_{4\times 4}$ and the relevant submatrices

$$\mathbf{V} = \begin{pmatrix} \mathbf{V_{uu}} & \mathbf{V_{uo}} \\ \mathbf{V_{uo}^T} & \mathbf{V_{oo}} \end{pmatrix},$$

where $\mathbf{V_{uu}}$ is the covariance matrix for unobservable $(u,\ I)$ variables, $\mathbf{V_{uo}}$ the covariance matrix between unobservable $(u,\ I)$ and observable $(u_i,\ D_i)$ variables, and $\mathbf{V_{oo}}$ the covariance matrix for observable $(u_i,\ D_i)$ variables. The expectation of both the cost-push shock and the instrument conditional on the information set of firm i is given by

$$\begin{aligned}
\mathbb{E}\left(\begin{matrix} u \\ I \end{matrix}\ \middle|\ u_i, D_i\right) &= \mathbf{\Omega}\begin{pmatrix} u_i \\ D_i \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}\begin{pmatrix} u_i \\ D_i \end{pmatrix} \\
&= \begin{pmatrix} \frac{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\phi^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} & \frac{\sigma_u^2\sigma_\rho^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} \\ \frac{\nu\sigma_u^2\sigma_\phi^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} & \frac{\nu(\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_\mu^2\sigma_\rho^2)}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_u^2\sigma_\phi^2+\sigma_\mu^2\sigma_\rho^2+\sigma_\rho^2\sigma_\phi^2} \end{pmatrix} \\
&\qquad \times \begin{pmatrix} u_i \\ D_i \end{pmatrix}, \qquad (7)
\end{aligned}$$

where $\mathbf{\Omega} = \mathbf{V_{uo}}\mathbf{V_{oo}^{-1}}$.

We express the price equation (6) as

$$p = \sum_{k=0}^{\infty}(1-\xi)^k\left[(1\ \ \xi)\mathbf{\Omega}\mathbf{\Xi}^k\begin{pmatrix} u \\ D \end{pmatrix}\right],$$

where the matrix $\boldsymbol{\Xi}$ is given by the first-order expectation of the cost-push shock u and the average central bank disclosure D:

$$\mathbb{E}\begin{pmatrix} u \\ D \end{pmatrix} \Bigg| \ u_i, D_i \Bigg) = \boldsymbol{\Xi}\begin{pmatrix} u_i \\ D_i \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \frac{1}{\nu}\Omega_{21} & \frac{1}{\nu}\Omega_{22} \end{pmatrix}\begin{pmatrix} u_i \\ D_i \end{pmatrix}.$$

The perfect Bayesian equilibrium yields the linear price setting of firm i (see the appendix for the derivation of optimal coefficients):

$$p_i = \gamma_1 u_i + \gamma_2 D_i \qquad \text{with} \tag{8}$$

$$\gamma_1 = \frac{\frac{(1-\xi)}{\nu}\gamma_2\Omega_{21} + \Omega_{11} + \xi\Omega_{21}}{1-(1-\xi)\Omega_{11}}$$

$$\gamma_2 = \frac{(1-\xi)\gamma_1\Omega_{12} + \Omega_{12} + \xi\Omega_{22}}{1-\frac{(1-\xi)}{\nu}\Omega_{22}}.$$

The optimal monetary policy consists of choosing the instrument (5) that minimizes the loss (3) subject to the price rule (8).

According to (3), the central bank minimizes the unconditional expected loss:

$$\mathbb{E}(L) = \text{var}(p) + \lambda \cdot \text{var}(y). \tag{9}$$

The optimal monetary policy will depend on the degree of the central bank's transparency. We derive the optimal monetary policy first under opacity and then under transparency.

4.3 Optimal Monetary Policy under Opacity

Under opacity ($\sigma_\phi^2 \to \infty$), firms do not observe the monetary instrument. They are, however, aware that the central bank responds to cost-push shocks according to its information, and they rationally use their private information u_i to infer the monetary instrument I.

In that case, the second column of $\boldsymbol{\Omega}$ in (7) consists of zeros, as the central bank's disclosure does not contain any valuable information. The solution to the inference problem of each firm boils down to

$$\mathbb{E}_i(u, I) = \mathbb{E}\left(\begin{matrix} u \\ I \end{matrix} \ \Bigg| \ u_i\right) = \begin{pmatrix} \Omega_1 \\ \Omega_2 \end{pmatrix} u_i = \begin{pmatrix} \frac{\sigma_u^2}{\sigma_u^2+\sigma_\rho^2} \\ \frac{\nu\sigma_u^2}{\sigma_u^2+\sigma_\rho^2} \end{pmatrix} u_i.$$

Plugging this into equation (6) yields

$$p = \sum_{k=0}^{\infty}(1-\xi)^k\left[\Omega_1^{k+1}(1+\xi\nu)u\right]$$
$$= \frac{\Omega_1(1+\xi\nu)}{1-(1-\xi)\Omega_1}u = \frac{\sigma_u^2}{\sigma_\rho^2+\xi\sigma_u^2}(1+\xi\nu)u = \gamma_1 u. \qquad (10)$$

The optimal monetary policy consists of choosing the instrument (5) that minimizes the unconditional expected loss (9) subject to the price rule (10). The variance of the price level is simply given by

$$\mathrm{var}(p) = \gamma_1^2\sigma_u^2,$$

while the variance of the output gap is

$$\mathrm{var}(y) = (\nu-\gamma_1)^2\sigma_u^2 + \nu^2\sigma_\mu^2.$$

The fixed-point solution to this optimization problem yields the following equilibrium price setting for firm i:

$$p_i = \gamma_1 u_i$$
$$= \frac{\lambda\sigma_u^2}{\xi\sigma_u^2+\sigma_\rho^2}\cdot\frac{\sigma_u^2\sigma_\rho^4+\xi^2\sigma_u^4\sigma_\mu^2+2\xi\sigma_u^2\sigma_\rho^2\sigma_\mu^2+\sigma_\rho^4\sigma_\mu^2+\xi\sigma_u^4\sigma_\rho^2}{\xi^2\sigma_u^6+\lambda\sigma_u^2\sigma_\rho^4+\lambda\xi^2\sigma_u^4\sigma_\mu^2+2\lambda\xi\sigma_u^2\sigma_\rho^2\sigma_\mu^2+\lambda\sigma_\rho^4\sigma_\mu^2}u_i,$$

while the optimal monetary policy satisfies

$$\nu = \frac{\lambda\sigma_u^4\sigma_\rho^2-\xi\sigma_u^6}{\xi^2\sigma_u^6+\lambda\sigma_u^2\sigma_\rho^4+\lambda\xi^2\sigma_u^4\sigma_\mu^2+2\lambda\xi\sigma_u^2\sigma_\rho^2\sigma_\mu^2+\lambda\sigma_\rho^4\sigma_\mu^2}. \qquad (11)$$

Interestingly, under opacity, the optimal monetary policy coefficient (11) can be positive or negative depending on the parameter configuration. As discussed above, cost-push shocks create a trade-off between price and output-gap stabilization. The central bank disclosure influences the reaction of the price level to monetary policy and thereby the trade-off the central bank faces. Opacity reduces the effectiveness of monetary policy on the price level as it increases fundamental and strategic uncertainty of firms about the central bank's action. Under opacity, the central bank's influence on the price level is limited, as firms do not observe its instrument. So, contracting the aggregate demand is ineffective to reduce the price level and the central bank may find it optimal to reduce the negative output gap (instead of the price level) by increasing aggregate demand (i.e., $\nu > 0$).

Yet opacity is not a sufficient condition for monetary policy to be accommodative. The sign of the policy coefficient (11) depends on the relation between the degree of strategic complementarities $1-\xi$, the preference of the central bank for output-gap stabilization λ, and the relative precision of firm's information σ_ρ^2/σ_u^2. In particular, the following condition holds:

$$\nu > 0 \Leftrightarrow \xi < \lambda \frac{\sigma_\rho^2}{\sigma_u^2}. \tag{12}$$

We propose to call the case where $\nu > 0$ the *blow with the wind* policy, according to which the central bank expands nominal aggregate demand whenever cost-push shocks are positive. We now discuss the conditions for $\nu > 0$.

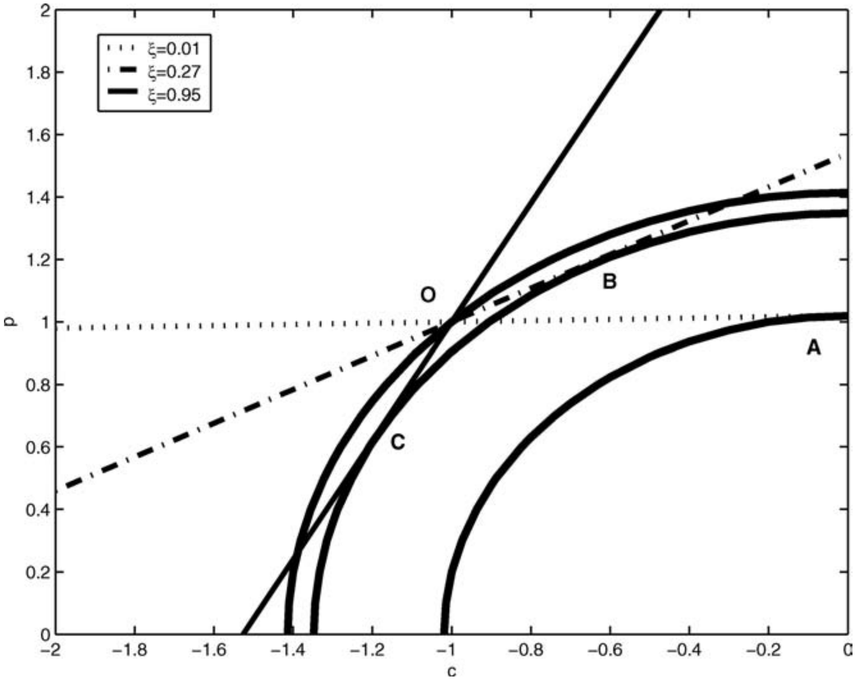
4.3.1 Degree of Strategic Complementarities

The policy coefficient is positive when complementarities are high (ξ low). As opacity alleviates the effectiveness of monetary policy on the price level, strong complementarities reduce it even further. When the degree of strategic complementarities in the economy is high, higher-order expectations are given an increasing weight in the price setting. This exacerbates strategic uncertainty about the monetary instrument that characterizes opacity and reduces the effectiveness of monetary policy to stabilize the price level. This renders price-level stabilization ineffective compared with output-gap stabilization, and the central bank then faces a trade-off that incites it to stabilize the output gap rather than the price level (i.e., $\nu > 0$).

4.3.2 Precision of Private Information

When the relative precision of firms' private information increases (σ_ρ^2/σ_u^2 falls), fundamental and strategic uncertainty of firms about the monetary instrument decreases. The reduction of uncertainty renders monetary policy more effective to stabilize the price level,

Figure 1. Phillips Curves and Economic Outcomes under Opacity: Impact of Strategic Complementarities



and the trade-off favors leaning against the wind. This increases the incentive of the central bank to reduce price deviation. Firms also respond more strongly to cost-push shocks with more accurate information. This implies that the strength of the central bank's response increases: the absolute value of the policy coefficient rises.

4.3.3 Central Bank's Preference

Finally, when the central bank is more inclined toward price stabilization, the incentive of the central bank to contract the nominal demand in order to reduce the price level increases in a very intuitive way. Then leaning against the wind is preferred to blowing with the wind.

We can now interpret former monetary policy issues in terms of Phillips curves, as shown in figure 1. The latter describe the price-output combinations the central bank can achieve with its policy. Since the degree of transparency drives the effectiveness of monetary policy to stabilize prices, it also shapes the slope of Phillips curves. Figure 1 is computed with $\sigma_\mu^2 = \sigma_\rho^2 = \sigma_u^2/2$ and $\lambda = 1$ ($\sigma_\phi^2 \rightarrow \infty$ under opacity) for three levels of strategic complementarities. As opacity enhances uncertainty about the monetary instrument, its effectiveness is driven by the degree of strategic complementarities $1 - \xi$ and the precision of firms' information σ_ρ^2/σ_u^2. More particularly, when complementarities are extremely strong or the precision of firms' information is nearly zero ($\xi \rightarrow 0$ or $\sigma_\rho^2 \rightarrow \infty$), the effectiveness of monetary policy on prices is highly limited and the corresponding Phillips curve is horizontal (dotted line). Suppose that the economic outcome in the absence of central bank intervention is written as O. When the central bank is opaque, the degree of complementarities relatively strong, and firms' information not too accurate, condition (12) says that the optimal monetary policy is expansive. The resulting economic outcomes are written as A and B in figure 1. Reducing complementarities or increasing precision of firms' information reduces uncertainty (or its impact) and raises the slope of the Phillips curve under opacity (dashed line and solid line in figure 1). When firms' information is very accurate ($\sigma_\rho^2 \rightarrow 0$), the curve is vertical. The slope of the Phillips curve determines whether the monetary policy is expansive (points A and B) or contractive (point C).

4.4 Optimal Monetary Policy under Transparency

This section derives the optimal monetary policy when the monetary instrument is common knowledge among firms. In the case of full transparency ($\sigma_\phi^2 = 0$), the solution to the inference problem of firm i is given by

$$\mathbb{E}\left(\begin{matrix} u \\ I \end{matrix} \middle| \; u_i, D\right) = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix} \begin{pmatrix} u_i \\ D \end{pmatrix}$$
$$= \begin{pmatrix} \frac{\sigma_u^2\sigma_\mu^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_\rho^2\sigma_\mu^2} & \frac{\sigma_u^2\sigma_\rho^2}{\sigma_u^2\sigma_\mu^2+\sigma_u^2\sigma_\rho^2+\sigma_\rho^2\sigma_\mu^2} \\ 0 & \nu \end{pmatrix} \begin{pmatrix} u_i \\ D \end{pmatrix}.$$

The equilibrium pricing rule (8) is described by

$$p_i = \frac{\sigma_u^2\sigma_\mu^2}{\xi\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\mu^2\sigma_\rho^2} u_i + \left[\frac{\sigma_u^2\sigma_\rho^2}{\xi\left(\xi\sigma_u^2\sigma_\mu^2 + \sigma_u^2\sigma_\rho^2 + \sigma_\mu^2\sigma_\rho^2\right)} + \nu\right] D. \tag{13}$$

Minimizing the unconditional expected loss (9) subject to firms' pricing rule (13) yields the following optimal monetary policy:

$$\nu = -\frac{1}{\xi}\frac{\sigma_u^2}{\sigma_u^2 + \sigma_\mu^2} < 0.$$

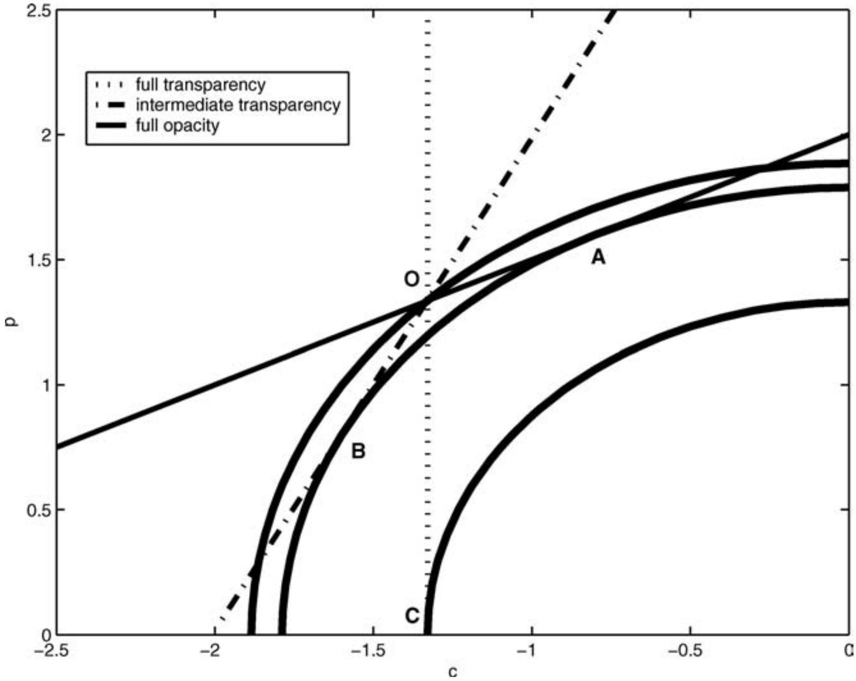
The optimal policy under transparency coincides with the standard monetary policy analysis consisting in leaning against the wind. Indeed, standard literature assumes that the instrument is common knowledge among firms (firms know the monetary instrument implemented by the central bank) but appears as a particular case in our framework (i.e., transparency case).

4.5 Increase in Central Bank Transparency

While the former analysis is restricted to extreme disclosure strategies (i.e., opacity vs. transparency), the current section discusses the case of intermediate levels of transparency ($0 < \sigma_\phi^2 < \infty$). More particularly, we examine the impact of an increase in transparency of the central bank's monetary instrument on the optimal monetary policy. We show that small variations in transparency or in the central bank's preferences can have large effects on the optimal conduct of monetary policy.

Figure 2 illustrates the economic outcome for different degrees of transparency. The parameter values are $\sigma_\mu^2 = \sigma_\rho^2 = \sigma_u^2/2$, $\xi = 0.25$, and $\lambda = 1$. The dotted line represents the possible price-output combinations for a fully transparent central bank. In this case, since monetary policy is common knowledge among firms, the Phillips curve is vertical. The solid line is the Phillips curve for full opacity. The dashed line represents an intermediate degree of transparency. The slope of the curve falls with strategic complementarities and rises with the precision of firms' private information and with the degree of transparency. Under opacity and when the curve is relatively flat, the optimal monetary policy is expansive and leads to the

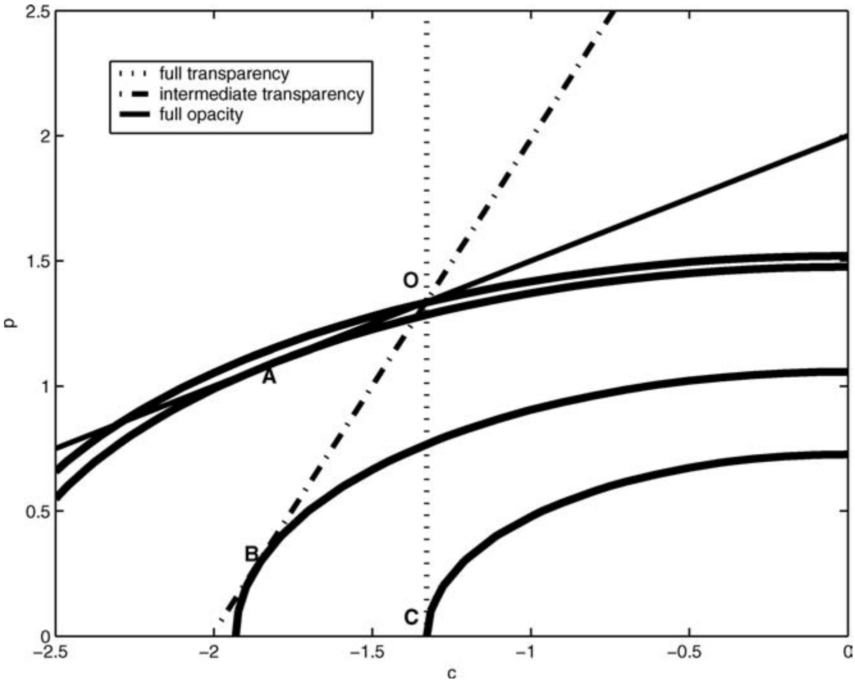
Figure 2. Phillips Curves and Economic Outcomes: Impact of Transparency ($\lambda = 1$)



economic outcome indicated by point A. Interestingly, this analysis suggests that a central bank acting under opacity and choosing the economic outcome written A goes for the blow against the wind policy: while inflation expectations rise because of a positive cost-push shock, the central bank expands nominal aggregate demand, which exacerbates the rise in inflation. Econometricians examining such time series would conclude, as do Clarida, Galí, and Gertler (2000) for the 1970s, that the central bank is accommodative. By contrast, when transparency increases or when complementarities weaken or when firms' information is more accurate, the Phillips curve becomes steeper. This yields a contractive optimal monetary policy (point B). Finally, with full transparency, the policy is always contractive and the outcome is given by C.

Figure 3 illustrates the case where the central bank is more inclined toward price stabilization. The parameter values are $\sigma_\mu^2 =$

Figure 3. Phillips Curves and Economic Outcomes: Impact of Transparency ($\boldsymbol{\lambda = 0.3}$)



$\sigma_\rho^2 = \sigma_u^2/2$, $\xi = 0.25$, and $\lambda = 0.3$. The optimal monetary policy may be restrictive even for an opaque central bank. Point A shows the outcome resulting from a contractive monetary policy.

5. Concluding Remarks

Our model highlights the relevance of a central bank's disclosure for the effectiveness of monetary policy in an economy characterized by strategic complementarities and heterogeneous information. The high inflation of the 1970s is usually rationalized within the Barro-Gordon framework. This literature presumes that the high-inflation episode comes from the incentive of the central bank to push the output above its natural level and to cheat the private sector. In this context, most of the literature has called for transparency in order to achieve credibility. In contrast, we show that, even in the absence of an inflationary bias, a credible central bank may find it optimal to accommodate monetary policy in response to a cost-push shock whenever the uncertainty surrounding its monetary instrument is high. In particular, central bank opacity linked to some preference for output-gap stabilization yields an optimal monetary policy that accommodates a cost-push shock. As the central bank faces a trade-off between price and output-gap stabilization, its disclosure influences the effectiveness of its policy and thus whether it will focus on price or on output-gap stabilization. An accommodating policy can be attributed to the lack of transparency and not necessarily to the lack of credibility. Second, our analysis highlights the fact that transparency is not just a means to enhance central bank credibility but also plays a crucial role in the optimality of monetary policy implemented by a fully credible central bank.

Appendix. Linear Pricing Rule

This appendix solves the perfect Bayesian equilibrium for the pricing rule of firms given by equation (8).

We first postulate, as in Morris and Shin (2002), that the optimal price of firm i is a linear combination of its two signals:

$$p_i = \gamma_1 u_i + \gamma_2 D_i. \tag{14}$$

The optimal weights γ_1 and γ_2 depend on firms' expectations about the pricing behavior of other firms. The conditional estimate of the average price is therefore given by

$$\mathbb{E}_i(p) = \gamma_1 \mathbb{E}_i(u) + \gamma_2 \mathbb{E}_i(D). \tag{15}$$

Plugging $E_i(p)$ into the pricing rule (2) and replacing the expectations of firm i about u, D, and I yields

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + u + \xi I] \\ &= (1-\xi)[\gamma_1 \mathbb{E}_i(u) + \gamma_2 \mathbb{E}_i(D)] + \mathbb{E}_i(u) + \xi \mathbb{E}_i(I) \\ &= (1-\xi)\left[\gamma_1(\Omega_{11}u_i + \Omega_{12}D_i) + \gamma_2\left(\frac{\Omega_{21}}{\nu}u_i + \frac{\Omega_{22}}{\nu}D_i\right)\right] \\ &\quad + \Omega_{11}u_i + \Omega_{12}D_i + \xi\Omega_{21}u_i + \xi\Omega_{22}D_i. \end{aligned}$$

Rearranging gives

$$p_i = u_i \left[(1-\xi)\left(\gamma_1\Omega_{11} + \gamma_2\frac{\Omega_{21}}{\nu}\right) + \Omega_{11} + \xi\Omega_{21}\right]$$
$$+ D_i \left[(1-\xi)\left(\gamma_1\Omega_{12} + \gamma_2\frac{\Omega_{22}}{\nu}\right) + \Omega_{12} + \xi\Omega_{22}\right].$$

Identifying the coefficients, we get

$$\gamma_1 = \frac{\frac{(1-\xi)}{\nu}\gamma_2\Omega_{21} + \Omega_{11} + \xi\Omega_{21}}{1-(1-\xi)\Omega_{11}}$$
$$\gamma_2 = \frac{(1-\xi)\gamma_1\Omega_{12} + \Omega_{12} + \xi\Omega_{22}}{1-\frac{(1-\xi)}{\nu}\Omega_{22}}.$$

This system of equations is equivalent to (8) in the main text.

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Stock Market Performance and Pension Fund Investment Policy: Rebalancing, Free Float, or Market Timing?*

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This article examines the impact of stock market performance on the investment policy of pension funds. We find that stock market performance affects the asset allocation of Dutch pension funds in two ways. In the short term, outperformance of equities over bonds and other investment categories automatically results in a higher actual equity allocation (and vice versa), as pension funds do not continuously rebalance their investment portfolios. Each quarter, pension funds rebalance, on average, around 39 percent of excess equity returns, leaving 61 percent for free floating. In the medium term, outperformance of equities induces pension funds to increase their strategic equity allocation (and vice versa). These findings suggest that the investment policies of pension funds are partially driven by the cyclical performance of the stock market. We also find that rebalancing is much stronger after negative equity

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returns, indicating that pension funds respond asymmetrically to stock market shocks. Furthermore, investment policies of large funds deviate from those of small funds: large funds hold more equity and their equity allocation is more strongly affected by actual equity returns, reflecting less rebalancing. The largest funds react highly asymmetrically to equity returns. Their positive excess equity returns lead to adjustments in equity portfolios of more than 100 percent, reflecting "overshooting" of free floating, or positive-feedback trading. Apparently, managers of large funds have greater risk tolerance, particularly in bull markets.

JEL Codes: G11, G23.

1. Introduction

The optimal equity allocation of pension funds is subject to considerable debate. A high percentage of assets invested in equities results in significant exposure of pension wealth to fluctuations in stock market prices. While nominal defined-benefit pension liabilities can be hedged by investing in the replicating portfolio of fixed-income securities, considerable equity holdings may be optimal when indexation of benefits is contingent on the funding ratio of the pension fund.[1] During the 1990s abundant equity returns led to premium reductions and even contribution holidays for pension plan sponsors. However, the risks of equity holdings surfaced after the collapse of the stock market in 2000–02, which resulted in large losses for pension funds. In reaction, pension benefits were curtailed and contributions steeply increased. This episode raised a debate on the investment strategies of Dutch pension funds and, particularly, on their exposure to equity markets.

[1]Nominal defined-benefit pension liabilities can be hedged by investing in the replicating portfolio of fixed-income securities such as nominal government bonds and interest rate swaps. In contrast, defined-benefit pension liabilities that are fully indexed to prices can be replicated by investing in inflation-linked bonds. In many Dutch defined-benefit pension deals, indexation is contingent on the funding ratio of the pension fund. The market value of this contingent indexation can be derived using option-pricing theory. In this case it might be optimal to have considerable equity exposure; see, e.g., Broeders (2006).

Table 1. Pension Fund Strategic and Actual Asset Allocation (1999:Q1–2006:Q4; in %)

Asset Classes	Average Strategic Asset Allocation	Standard Deviation	Average Actual Asset Allocation	Standard Deviation
Equities	42	15	41	15
Bonds	39	20	45	19
Real Estate	10	6	10	6
Cash	1	11	1	10
Other	8	11	3	11
Total	*100*		*100*	

Note: The asset shares are averages over Dutch pension funds, weighted by total investments.
Source: De Nederlandsche Bank.

The investment strategy of Dutch pension funds is of key importance to society, as it involves more than €600 billion in assets, or over €37,500 per inhabitant. The way in which these assets are invested has a significant influence on the level of required premiums or final benefits. A 1 percent lower annual return over the life cycle of a typical worker translates into 27 percent lower accumulated pension assets.[2] Consequently, one of the most important responsibilities of pension funds' trustees is to maximize the expected return on assets at an acceptable level of risk, e.g., measured in terms of the probability of underfunding.

This study investigates whether stock market performance influences pension funds' investment policies. In particular, we examine two ways in which stock market performance impacts the equity allocation of pension funds: (i) in the short term, as a result of market timing or imperfect rebalancing, and (ii) in the medium term, as a result of adjustments to the strategic asset allocation.

Table 1 presents the asset allocation of Dutch pension funds over the following five broad classes: equities, bonds, real estate, cash, and other assets. Pension fund investment policy includes the strategic

[2]The three main components determining the costs of pensions are the quality of the pension scheme, the rate of return on investments, and administrative and investment costs (see also Bikker and De Dreu 2009).

asset allocation decision, which refers to choosing the investment percentages in each asset class. Of the aforementioned asset classes, equities have the highest expected return but also the highest volatility. For most pension funds, equities are the largest asset category. Consequently, equity allocation is one of the key policy variables determining the risk-return profile of a given pension fund.

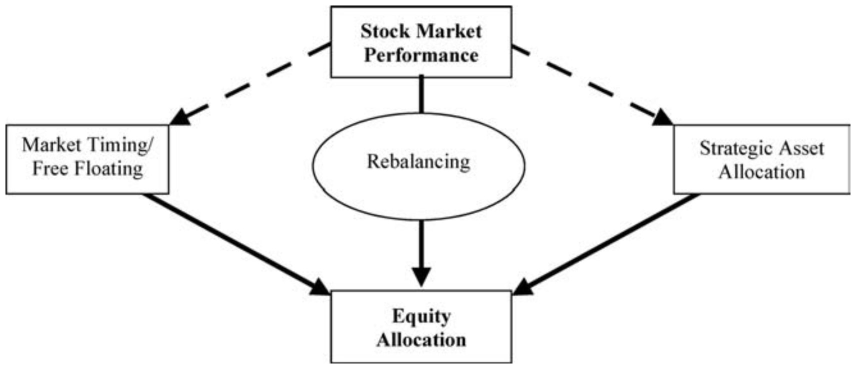
Pension funds generally determine their strategic asset allocation policies using asset and liability management studies, in which they consider long-term expected returns, return variances, and covariances of broad asset classes, given the size and characteristics of their pension liabilities; see, e.g., Campbell and Viceira (2002).[3] The strategic asset allocation is typically set on a three- to five-year horizon. For many pension funds, the strategic asset allocation includes bandwidths for the actual asset allocation to drift. For this purpose a tactical risk budget can be made available. These bandwidths are chosen in such a way that the maximum ex ante tracking error does not exceed a given threshold. This tracking error (TE) is usually defined as $TE = w'\Sigma w$, where w is the vector of actual portfolio weights minus the vector of strategic portfolio allocation and Σ is the variance-covariance matrix. In this article, rebalancing is interpreted as a return to the midpoint of these bandwidths.

As investment opportunities change over time, deviations in expected returns from their long-term averages may warrant changes in the investment mix.[4] Choosing actual portfolio weights that deviate from the strategic asset allocation is known as "tactical asset allocation" or "market timing." Market timing refers to taking short-term (informed) bets on the relative asset class returns. It can be implemented through actually buying and selling the underlying securities, although in practice, derivatives are also commonly used as an efficient way to change a fund's asset allocation. However, the potential extra return through market timing is limited, as indicated

[3]Shefrin and Statman (2000) use behavioral finance theory to explain the asset allocation of pension funds. They argue that investors build portfolios as pyramids of assets, layer by layer. In contrast to mean-variance theory, covariance between asset classes is generally ignored, resulting in suboptimal portfolios.

[4]Predictability in expected asset returns may affect the optimal portfolio choice of investors with long horizons (see, e.g., Barberis 2000; Pastor and Stambaugh 2001).

Figure 1. The Impact of Stock Market Performance on Equity Allocation



also by the so-called fundamental law of active management; see Grinold and Kahn (1999).[5]

This study examines the impact that higher or lower returns on stocks compared with the other asset categories have on the equity allocation of pension funds. To the best of our knowledge, this is the first study that examines this relationship. Figure 1 shows the various factors that influence the equity allocation of pension funds. Over the long term, equity allocation is determined by a fund's strategic asset allocation. However, several factors influence asset allocation in the short to medium term. We distinguish the following three equity investment strategies that pension funds may use to

[5]This law states that the information ratio equals the information coefficient times the square root of the number of independent investment decisions. The information ratio is the risk-adjusted excess return over a passive investment strategy. An information ratio of 0.5, which is considered high, requires that asset managers earn a 50-basis-points excess return ("alpha") per 1 percent of residual risk on a yearly basis. The information coefficient measures the skill of the asset manager and is defined as the correlation between his forecasts on investment returns and the actual outcomes. The number of independent investment decisions is four, if the pension fund makes quarterly market-timing decisions. To generate a market-timing information ratio of 0.5 requires, in that case, an information coefficient of 0.25, which is considered extremely high. It would require the asset manager to forecast the direction of the stock market correctly 63 out of 100 times and adjust his portfolio likewise. Therefore, the potential added value of market timing is limited. In addition, such a strategy would involve (substantial) transaction costs.

respond to positive or negative stock market returns: rebalancing, free float, and market timing.

Rebalancing refers to the investment process applied to ensure that a fund's actual equity allocation continuously equals its strategic equity allocation, which implies selling equities after relatively high stock market returns and buying after relatively low equity returns. This might also be indicated as a form of negative-feedback trading, referring to buying past losers and selling past winners; see, e.g., Lakonishok, Schleifer, and Vishny (1992). This form of trading is commonly a part of the argument that institutional investors stabilize asset prices. By contrast, we use *free float* to indicate a passive investment strategy, in which pension funds allow their equity allocation to drift with market developments.[6] Finally, as mentioned above, *market timing* refers to a temporary higher or lower weighting of equities (or other asset classes) relative to the pension fund's strategic asset allocation, motivated by short-term return expectations. Note that where no equity trades are made, it is difficult to distinguish between free float (passive management) and market timing (active management), as allowing the asset allocation to drift could be seen as an active investment decision.

A number of studies show that strategic asset allocation dominates portfolio performance. In particular, strategic asset allocation is shown to explain more than 90 percent of the variability in pension fund returns over time, while the additional variation explained by market timing is less than 5 percent (Blake, Lehmann, and Timmermann 1999; Brinson, Hood, and Beebower 1986; Brinson, Singer, and Beebower 1991; Ibbotson and Kaplan 2000). Moreover, in line with the efficient-market theory, evidence shows that pension funds are unsuccessful in exploiting market timing to generate excess returns. In particular, market timing is shown to cause an average loss of 20–66 basis points per year (Blake, Lehmann, and Timmermann 1999;

[6]Pension funds can rebalance continuously, thereby ensuring that their asset allocation always matches their strategic asset allocation. However, pension funds are known to use rebalancing strategies, which have some free-float component. Examples include *calendar* rebalancing, whereby pension funds rebalance their portfolio back to its strategic weights at regular intervals, and *band rebalancing*, whereby pension funds create bands around each asset class and rebalance their portfolio as soon as one asset class breaches its band.

Brinson, Hood, and Beebower 1986; Brinson, Singer, and Beebower 1991; Daniel et al. 1997).

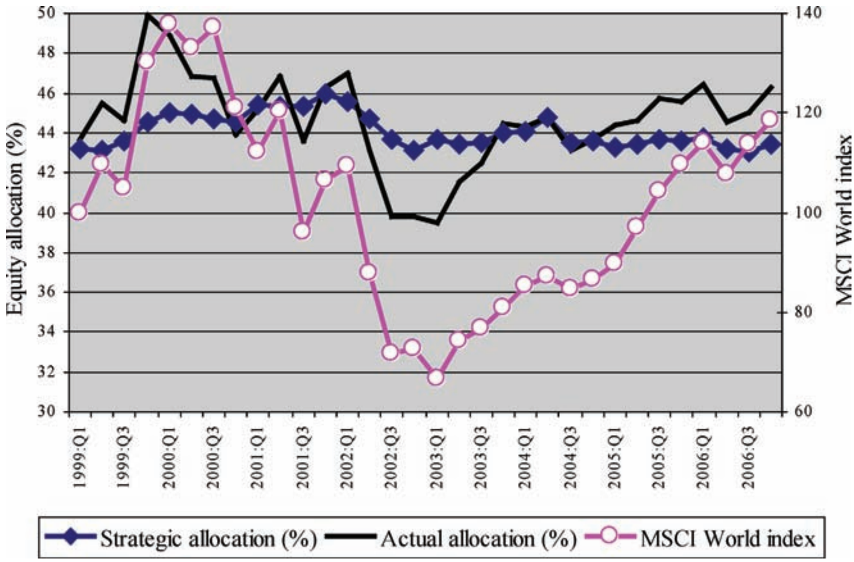
While a number of empirical studies examine the impact of investment policy on returns,[7] very few papers investigate the impact of market developments on investment policy. Blake, Lehmann, and Timmermann (1999) and Kakes (2006) report a negative correlation between asset class returns and net cash flows to the corresponding asset class, which points to rebalancing. However, Blake, Lehmann, and Timmermann (1999) also find that the asset allocation for UK pension funds drifts toward asset classes that performed relatively well, in line with a free-float strategy. Apparently, UK pension funds only partly rebalanced their investments in response to different returns across asset categories. Hence, the degree of rebalancing versus free float in pension fund asset allocation remains an open question.

This article uses quarterly data from Dutch pension funds over 1999:Q1–2006:Q4. Although this period is relatively short, it contains a significant stock market bubble as well as a burst. Figure 2 presents a preview of the empirical results, depicting the strategic and the actual equity allocation for Dutch pension funds, as well as the MSCI World Index. Three patterns stand out from this figure. First, the actual equity allocation tends to have a pattern similar to the MSCI World Index but with some reversion to the strategic asset allocation. Generally, actual equity allocation increases when the stock market goes up, and vice versa. The main explanation for this pattern is that pension funds tend to rebalance their asset allocation only partly in response to changes in the value of their equity portfolio.

Second, figure 2 points to interaction between stock market performance and strategic asset allocation. The strategic equity allocation appears to follow the performance of the equity market,

[7]The literature investigating the effectiveness of stock picking and market timing in improving investment performance is extensive. Most studies focus on U.S. mutual funds and find that fund managers are not able to exploit selectivity and timing to generate excess returns (e.g., Fama 1972, Henriksson and Merton 1981, Kon 1983, and Kon and Jen 1979). Agnew, Balduzzi, and Sundén (2003) report that equity allocations of participants in 401(k) plans are positively related to the previous day's equity return (feedback trading). However, no significant correlation is found between changes in equity allocations and returns over the following three days, suggesting the absence of market-timing abilities.

Figure 2. Stock Market Returns and Equity Investments (1999:Q1–2006:Q4)



although only gradually and with a time lag. Following the stock market boom in the second half of the 1990s, the strategic equity allocation increased until the end of 2001 but decreased from 2002 to 2003 in response to the fall of the stock market that started in 2000. A possible explanation is that pension funds adjust their investment policies based on recent stock market performance. Positive excess returns increase the pension fund's buffer so that, as a consequence, regulatory rules also allow for a higher proportion of the more risky equity investments. Apparently, pension funds make use of this opportunity and adjust their strategic asset allocation accordingly.

Third, the figure suggests that pension funds may have lost money from market timing over the business cycle. They seem to have gradually increased their equity allocation until the downturn of the stock market was well under way, confronting them with relatively large losses. Conversely, pension funds did not significantly increase their equity allocation portfolio investments to reap the full benefit of the subsequent upward stock market trend.

The structure of this article is as follows. Section 2 presents the data used in the analyses. Section 3 investigates the influence of market movements on asset allocation, whereas rebalancing is more closely examined in section 4. The next section analyzes the relationship between stock market returns and strategic asset allocation. Finally, the last section summarizes and concludes.

2. Description of the Data

We use a detailed data set with quarterly information on all Dutch pension funds for the 1999:Q1–2006:Q4 period. The data is from De Nederlandsche Bank, responsible for the prudential supervision of the pension funds and their regulatory compliance. For each pension fund, data is available on strategic asset allocation, asset sales and purchases, the market value of investments in different asset classes, and their time-weighted returns. We use self-reported returns, as well as the MSCI World total return index denominated in euros, to assess the impact of equity returns on actual and strategic equity allocation. The sample is an unbalanced panel, as not all pension funds reported data for the entire sample period due to new entrants, mergers, terminations, and reporting failures. Since our aim is to study asset allocation over time, we exclude pension funds with less than two years of data. Finally, we exclude inconsistent observations and observations with clear reporting errors.

Our final sample includes data on 748 pension funds from 1999:Q1–2006:Q4, representing around 85 percent of total pension fund assets in the Netherlands. Table 2 presents summary statistics on the investment portfolios of pension funds in our sample. The size of pension funds in the sample is hugely divergent: the smallest pension funds have assets worth less than €1 million, while the largest fund has assets of more than €200 billion. The average and median sizes of pension fund assets equal €799 million and €53 million, respectively. We distinguish between size classes and types of pension funds and between types of pension plans. Small funds tend to invest relatively less in equity compared with larger funds, and more in bonds, reflecting lower risk appetite. Although large in number (70 percent of the sample), small funds administer only a minor share (less than 3 percent) of all pension fund investments.

Table 2. Investments across Size Classes and Pension Fund Types (1999:Q1–2006:Q4)

Size Classes Based on Total Investments (Mln. Euro)	**Number of Pension Funds (1)**	**Average Total Investments (Mln. Euro) (2)**	**Average Bond Invest-ments (%) (3)**	**Average Equity Invest-ments (%) (4)**	**Max–Min Actual Equity Investments over Time (%) (5)**	**Max–Min Strategic Equity Allocation over Time (%) (6)**	**Investment Gap (%)[a] (7)**
0–100 (Small)	524	29	62	29	18	12	0.4
100–1,000 (Medium)	177	320	51	37	18	13	0.2
>1,000 (Large)	47	8,276	37	43	16	13	0.8
Total/Average	*748*	*799*	*39*	*42*	*16*	*13*	*0.8*
Type of Pension Fund[b,c]							
Industry (All)	95	3,798	35	41	14	12	1.1
Compulsory	76	4,412	36	41	14	12	1.1
Non-Compulsory	19	1,099	35	45	16	15	1.7
Company	631	280	45	43	20	13	0.1
Professional Group	10	2,292	51	42	18	12	0.5
Plan Type[c]							
Defined Benefit	592	926	39	42	16	13	0.8
Defined Contribution	56	78	51	37	19	14	0.3

Note: All statistics are averages weighted by total investments except for the first two columns (Number of Pension Funds and Average Total Investments).

[a]Investment gap is the absolute difference between the strategic equity allocation and the actual percentage of equity portfolio investments.

[b]Ten pension funds belong to other categories.

[c]For some pension funds, type of pension fund or dominant plan type are unknown.

Our sample includes 631 company funds, 95 industry-wide funds, and 10 professional group funds.[8] Compulsory industry funds are largest in terms of investments. All pension fund categories invest between 41 and 45 percent in equity. Company funds and professional group funds invest relatively more in bonds than other types of funds, reflecting their stronger risk aversion. Industry funds invest substantially more in real estate. On average, defined-benefit funds have higher equity and lower bond investments than defined-contribution funds, suggesting that defined-benefit funds may take higher risks since they can benefit from intergenerational risk sharing.

Columns 5 and 6 indicate how, respectively, the actual and strategic equity allocation vary over time. For the average pension fund, the range of the actual equity allocation is 16 percent and that of the strategic equity allocation is 13 percent. Thus, both actual and strategic equity allocation move significantly over time. The last column shows that the difference between strategic and actual equity allocation is, on average, 0.8 percentage point.

Table 3 shows that the strategic and actual equity allocation differ significantly across pension funds. A small majority of funds invest 20–40 percent of their assets in equities. A quarter of the funds invest more than 40 percent in equities, while around one-fifth of the funds invest less than 20 percent in equities.

3. Relative Stock Market Returns and Short-Term Changes in Equity Allocation

To start our empirical analysis, this section examines the short-term impact of stock market performance on equity allocation. Over time, actual equity allocation may change either (i) due to excess returns on equities compared with other asset classes (free floating) or (ii) due to net purchases or net sales of equities (rebalancing and market

[8]Company funds provide pension plans to the employees of their sponsor company. They are separate legal entities but are run by the sponsor company and employee representatives. Industry funds provide pension plans for employees working in an industry. Such pension plans are based on a collective labor agreement between an industry's companies and the labor unions, representing the employees in this industry. Finally, professional group funds offer pension schemes to specific professional groups (e.g., general practitioners, public notaries).

Table 3. Frequency Distribution of Equity Allocation across Pension Funds (1999:Q1–2006:Q4; in %)

Investment-in-Equity Classes	Frequency Distribution of Pension Funds, Based on Their:	
	Equity Allocation Strategy	**Actual Equity Allocation**
0–20	15.2	20.4
20–40	55.6	53.6
40–60	26.3	23.8
60–80	2.4	1.9
80–100	0.4	0.3
Total	*100.0*	*100.0*

timing). To investigate the impact of relative stock market returns on pension funds' equity allocation, we estimate the following equation:

$$w_{i,t} = \alpha_1 + \Sigma_{j=0}^{k} \beta_j \left(r_{t-j}^{E} - r_{i,t-j}^{T}\right) + \gamma_1 Policy_{i,t-1} + \delta_1 Size_{i,t-1} + \lambda_1 Funding_{i,t-1} + \varepsilon_{i,t}. \quad (1)$$

The dependent variable $w_{i,t}$ is the actual percentage of the portfolio invested in equities of pension fund i ($i = 1, \ldots, N$) at quarter t ($t = 1, \ldots, T$). The variable $(r^E - r^T)$ is used to measure excess stock market returns compared with other investment categories on a quarterly basis. For stock market return (r^E) we use either the return on the MSCI World equity index or the pension funds' self-reported equity performance. For the average return on the pension fund portfolio's other asset categories (r^T), we multiply the strategic asset allocation of four key asset classes by representative broad market indexes.[9] Again, the alternative is to use the pension funds'

[9]We consider five investment categories: equities, bonds, real estate, money market instruments, and other assets. For bonds we use the JP Morgan EMU bond index, for real estate we use the FTSE EPRA Netherlands real estate index, and for money market investments we use the three-month Euribor interest rate. We assume that the fifth category, "other assets," is proportionally invested in the previous four investment categories (or has a similar return). We calculate excess returns as follows: excess return = return MSCI − [(return on bonds * bond investments + return on real estate * real estate investments + three-months Euribor * money market investments)/(bond investments + real estate investments + money market investments)].

self-reported performance on the respective asset classes. We consider two variants of equation (1). The base model is without lagged stock market returns ($k = 0$), whereas alternatively, we include excess stock market returns with time lags ($k = 5$) to investigate the influence of past returns on pension funds' equity investments. The strategic equity allocation (*Policy*), also expressed as a percentage, is included to control for pension fund investment policy. *Size*, which is measured as the logarithm of the total investment portfolio, controls for the tendency of larger funds to invest relatively more in equities. *Funding*, calculated as total investments/discounted pension liabilities, is included because funds with a higher buffer are allowed to invest more in equities. *Policy, Size*, and *Funding* are included with one time lag to avoid endogeneity problems and since it may take some time before changes in these variables lead to changes in the equity portfolio investment. As stated before, the panel is unbalanced, which implies that the number of observations varies across pension funds.

3.1 Empirical Results of the Impact of Stock Returns on Actual Equity Allocation

Table 4 presents estimates of the impact of short-term excess stock returns on the percentage of equity portfolio investments, using equation (1). The measure of excess stock returns in this table is based on the pension funds' self-reported asset returns. A 1-percentage-point outperformance of the pension funds' equities leads to a significant increase in equity allocation of 0.12 percentage point in the subsequent quarter (first column). The second column shows that excess equity returns also have a (highly) significant impact on the equity allocation up to five quarters later. The impact decreases over time, indicating that pension funds rebalance gradually or infrequently. If a pension fund invests 40 percent in equity, a 1 percent rise of stock prices would imply an increase of the weight of stocks by 0.24 percentage point (being 40.4/100.4 minus 40/100)—that is, as long as no adjustments are made. In this example, the observed 0.12-percentage-point effect of excess returns on pension funds' equity implies that only half the excess is rebalanced and that the other half of the equity weight moves in tandem with stock prices.

Table 4 reveals also that a 1-percentage-point increase in the strategic equity allocation causes a significant rise of around

Table 4. Estimates of the Pension Funds' Equity Investments Model (1999:Q2–2006:Q4)

	All Funds		Small Funds	Medium-Sized Funds	Large Funds
	(1)	(2)	(3)	(4)	(5)
Excess Return	0.118***	0.103***	0.094***	0.109***	0.125***
Idem, Lagged 1 Quarter		0.067***	0.068***	0.069***	0.056***
Idem, Lagged 2 Quarters		0.053***	0.055***	0.052***	0.054***
Idem, Lagged 3 Quarters		0.031***	0.023***	0.037***	0.042***
Idem, Lagged 4 Quarters		0.023***	0.020***	0.024***	0.037***
Idem, Lagged 5 Quarters		0.018***	0.014**	0.020***	0.028**
Investment Policy $(t-1)$	0.900***	0.910***	0.931***	0.900***	0.884***
Size $(t-1)$	0.001***	0.001**	0.002***	−0.004***	0.005***
Funding Ratio $(t-1)$	0.025***	0.016***	0.011***	0.025***	0.011***
Intercept	−0.009***	0.009***	−0.009	0.058***	−0.043**
Number of Observations	11,045	9,358	4,308	3,855	1,195
R^2, Adjusted	0.86	0.87	0.85	0.85	0.86

Notes: ***, **, and * denote significance at the 1, 5, and 10 percent significance levels, respectively. The standard errors have been corrected for possible heteroskedasticity or lack of normality using the Huber-White sandwich estimators. Estimates for excess returns are based on data reported by pension funds.

0.90 percentage point in actual equity portfolio investments in the next period. As one would expect, pension fund investment managers adjust their equity portfolio investments almost fully in response to changes in the strategic equity allocation. The positive sign for the size of investments affirms that larger funds invest relatively more in equities (see also table 1), except within the medium-sized funds class, where the sign becomes negative. A possible explanation is that large pension funds tend to be less risk averse than small pension funds, which also holds within the classes of small and large funds. Finally, in line with expectations, the funding ratio has a highly significant positive coefficient, indicating that funds with larger buffers invest more in equities. As equities are more risky, regulation requires larger buffers for this asset class.

If we consider the investment behavior across size classes (last three columns), where size classes are defined as in table 2, we observe that the impact of excess stock market returns on equity allocation increases with the pension fund size, both immediately and in the long run. Apparently, large funds allow more free floating, whereas smaller funds rebalance more. In line with this result, larger funds react less to changes in the investment policy, compared with smaller funds.

4. Excess Stock Market Returns and Rebalancing

The positive impact of excess equity returns on equity allocation in the previous section may be (partly) due to imperfect rebalancing by pension funds. Excess equity performance will automatically lead to changes in equity allocation if pension funds do not actively rebalance their investment portfolios fully. This section presents an empirical rebalancing model, which is used to estimate to what extent pension funds rebalance—that is, readjust—their asset allocation in response to excess equity returns.[10] This model is derived as follows, starting from the definition of the actual equity allocation:

$$w_{i,t} = E_{i,t}/TA_{i,t}, \tag{2}$$

[10] An alternative approach to measure rebalancing based on pension' funds equity sales and purchases is presented in the appendix.

where $E_{i,t}$ represents the equity investments of pension fund i at time t, and TA stands for total assets. Taking first differences of equation (2), we obtain

$$\begin{aligned} & w_{i,t} - w_{i,t-1} \\ & \quad = \frac{E_{i,t}}{TA_{i,t}} - \frac{E_{i,t-1}}{TA_{i,t-1}} = \frac{E_{i,t-1}\left(1 + r^E_{i,t} + NCF^E_{i,t}\right)}{TA_{i,t-1}\left(1 + r^T_{i,t} + NCF^T_{i,t}\right)} - \frac{E_{i,t-1}}{TA_{i,t-1}} \\ & \quad = w_{i,t-1}\frac{\left(1 + r^E_{i,t} + NCF^E_{i,t}\right)}{\left(1 + r^T_{i,t} + NCF^T_{i,t}\right)} - w_{i,t-1}\frac{\left(1 + r^T_{i,t} + NCF^T_{i,t}\right)}{\left(1 + r^T_{i,t} + NCF^T_{i,t}\right)} \\ & \quad = w_{i,t-1}\frac{\left(r^E_{i,t} - r^T_{i,t} + NCF^E_{i,t} - NCF^T_{i,t}\right)}{\left(1 + r^T_{i,t} + NCF^T_{i,t}\right)}, \end{aligned} \tag{3}$$

where NCF^T is short for Net Cash Flows converted into new investments as a fraction of total investments, NCF^E for new equity investments also as a fraction of equity investments, r^E for the return on equities over the last quarter, and r^T for the return on total assets (all for fund i and quarter t). Dividing both sides by $w_{i,t-1}$ results in

$$\frac{w_{i,t} - w_{i,t-1}}{w_{i,t-1}} = \frac{r^E_{i,t} - r^T_{i,t}}{1 + r^T_{i,t} + NCF^T_{i,t}} + \frac{NCF^E_{i,t} - NCF^T_{i,t}}{1 + r^T_{i,t} + NCF^T_{i,t}}. \tag{4}$$

This equation explains the percentage change in equity allocation by (i) excess equity returns and (ii) net cash flows to equities, where both variables are scaled by the change in the total portfolio size. The first right-hand term is exogenous, since excess returns are determined by market developments and net cash flows into the pension fund are based on (previously made) decisions by employers and employees rather than on equity allocation. Given the small size of pension fund investments relative to total stock market capitalization, we can safely assume that changes in equity allocation do not affect stock market returns. The second right-hand term, however, is endogenous. While net cash flows to equity investments directly influence the equity allocation of pension funds, the reverse can also be true: changes in the equity allocation may sway pension funds to adjust their net cash flows to equity investments. Thus, there is mutual causality between changes in equity allocation and net cash flows to equity investments. To estimate the impact of excess equity returns on equity allocation, we apply the above decomposition, ignoring the endogenous second right-hand term. This results in the following empirical regression model:

$$\frac{w_{i,t} - w_{i,t-1}}{w_{i,t-1}} = \alpha_2 + \beta_2 \left(\frac{r^E_{i,t} - r^T_{i,t}}{1 + r^T_{i,t} + NCF^T_{i,t}} \right) + \gamma_2 \left(\frac{\Delta Policy_{i,t-1}}{Policy_{i,t-2}} \right) + \varepsilon_{i,t}. \tag{5}$$

The percentage change or growth in the strategic equity allocation (*Policy*) is included to control for changes in investment policy. This variable is included with a time lag of one quarter, since it may take some time before changes in policy lead to adjustments in the actual equity portfolio investments. In equation (5), β_2 estimates the degree of free float or market timing so that $1 - \beta_2$ assesses the rebalancing percentage. As an alternative model, we split the excess equity return variable into positive and negative equity returns. This allows us to observe possible asymmetric effects in response to changes in excess equity returns.

4.1 Empirical Results of Rebalancing

Table 5 presents the estimated impact of excess equity returns on equity allocation. The results show that pension funds rebalance, on average, around 39 percent of excess equity returns, leaving 61 percent for free floating. Thus 61 percent of excess equity returns translate into increases of the equity allocation in the next period. This is roughly in line with what we have observed in table 4. Column 2 shows that pension funds rebalance differently in response to positive and negative equity returns. Only 13 percent of positive equity returns are rebalanced, against 49 percent of negative equity returns. Apparently, whereas pension funds do not automatically sell equities in bull markets, they do tend to buy additional equities in bear markets. In line with expectations, changes in policy affect the actual allocation positively (significant at the 1 percent significance level), with a lag of one quarter.

Columns 3–8 present the model estimates for the various size classes. In line with the results of section 3.1, we observe that, in the symmetric model variant, large funds, at 32 percent, rebalance

Table 5. Estimates of the Equity Allocation Model: Rebalancing versus Free Float (1999:Q2–2006:Q4)

	All Funds		Small Funds		Medium-Sized Funds		Large Funds	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Excess Equity Returns	0.613		0.621		0.586		0.680	
Positive Excess Equity Returns		0.872		0.839		0.842		1.209
Negative Excess Equity Returns		0.508		0.532		0.482		0.483
Change in Policy ($t-1$)	0.075	0.076	0.109	0.109	0.020	0.022	−0.018	−0.015
Intercept	0.012	0.003	0.014	0.007	0.010	0.001	0.007	−0.008
Number of Observations	12,010	12,010	5,889	5,889	4,705	4,705	1,416	1,416
R^2, Adjusted	0.19	0.20	0.17	0.18	0.22	0.23	0.29	0.32

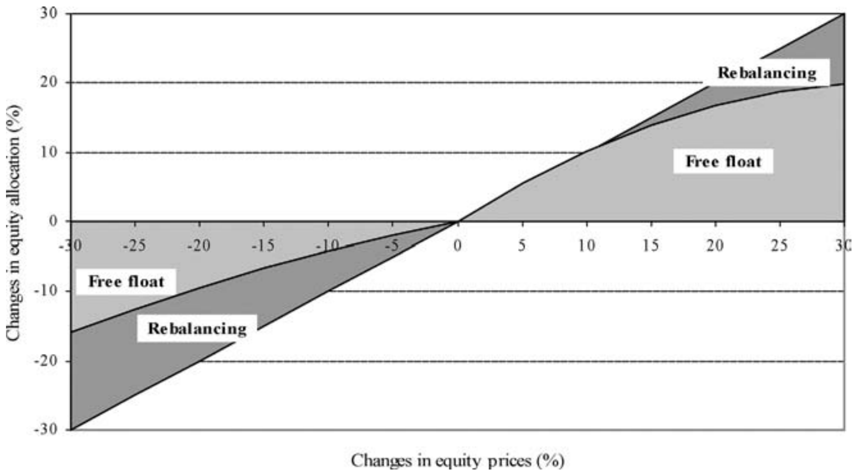
Notes: All symmetric and asymmetric excess equity returns effects are significant at the 1 percent significance level. The standard errors have been corrected for possible heteroskedasticity or lack of normality using the Huber-White sandwich estimators. Estimates for excess returns are based on data reported by pension funds.

less than the small and medium-sized funds (around 40 percent). Consequently, large funds leave 68 percent for free floating. Changes in the one-quarter-lagged strategic equity allocation (*Policy*) affect actual allocation significantly (at the 1 percent significance level) for the small funds only. If we turn to the asymmetric effects on excess equity returns, we observe that the positive effects increase significantly with pension fund size, while the negative effects are similar across the size classes. The positive-returns coefficient for the largest funds is, at 1.21, even above 1, indicating that large funds invest additional funds in equities in response to positive excess returns in the last month. This suggests that excess equity returns are perceived by large pension funds to provide a positive signal for future returns, leading pension funds to increase their stakes. This is in line with results in table 4, which indicate that large funds respond more strongly to excess equity returns than small ones. A possible explanation is that managers of large funds have more freedom to use market-timing strategies in response to market developments. Quite remarkable, we observe that the strategic equity allocation (although increasing for small and medium-sized pension funds) is not increasing for large pension funds; e.g., compare 1999 with 2006. This holds also for the actual equity allocation. Hence, the overshooting for large funds, as we have estimated in our paper, is apparently not due to an increase in the strategic asset allocation over time.

Figure 3 presents the asymmetric relation between excess equity returns and rebalancing discussed above.[11] If pension funds used a free-float strategy and did not rebalance at all, excess equity returns would go in full to proportionate increases in equity allocation. This is represented by the diagonal line. Instead, with full rebalancing, excess equity returns would have no impact on equity allocation, marked off on the x-axis. The curvature dividing the free-float and rebalancing areas reflects the actual rebalancing behavior of Dutch pension funds. Strikingly, rebalancing by pension funds depends on both the sign and size of excess equity returns. Small positive equity returns (of around 0 to 5 percent) are not rebalanced at all, but the degree of rebalancing increases with the size of excess equity

[11]To estimate this figure we adjusted equation (5) by adding three additional terms: squared excess equity returns and excess and squared equity returns multiplied with 0–1 dummies indicating positive and negative returns.

Figure 3. Reaction of Pension Funds to Excess Equity Returns: Rebalancing and Free Float



returns. Instead, small negative returns (of around 0 to −10 percent) are rebalanced for the largest part, but the degree of rebalancing decreases with the size of negative excess returns.

5. Excess Stock Market Returns and Medium-Term Changes in Strategic Equity Allocation

The previous two sections described the effects of excess equity returns on actual equity allocation. This section investigates the impact of (annual) stock market performance ($ar^E - ar^T$) on pension funds' strategic equity allocation (*Policy*). Therefore, we estimate the following equation:

$$Policy_{i,t} = \alpha_3 + \beta_3\left(ar^E_{i,t} - ar^T_{i,t}\right) + \gamma_3 Policy_{i,t-1} + \delta_3 Size_{i,t-1} + \varepsilon_{i,t}. \quad (6)$$

The excess stock market performance has been taken on an annual basis, indicated by ($ar^E - ar^T$), where a refers to annual. We assume that the pension fund trustees base their policy on longer-term measures of performance, as also reflected by the empirical results. As above, *Size* controls for the tendency of larger funds to invest relatively more in equity portfolios. We also include a lag of the dependent variable *Policy*, as we expect only gradual changes in policy over time. Hence, the equation describes the quarterly adjustments in policy.[12]

5.1 Empirical Results of the Impact of Stock Market Returns on Strategic Equity Allocation

Table 6 shows the impact of excess stock market returns on strategic equity allocation. The investment policy is adjusted significantly in response to changes in equity returns, irrespective of whether they are measured by the MSCI or by the actual investment returns earned by pension funds. This shows that investment policy is not constant over time but, to some extent, follows market developments. The coefficient of the lagged dependent variable, 0.97, indicates that slowly the strategic equity allocation reacts only to a small extent to changes in the quarterly returns. On average, 97 percent of the equity investment policy is determined by the previous quarter's investment policy, whereas market developments account for the remaining 3 percent. These market developments, captured by the yearly excess return, have a small but very significant impact, both based on the MSCI and on the actual equity return of the pension fund. Their final impact on equity investment policy over time is $0.25 (= 0.007/(1 - 0.972))$.

The size effect is also small but significant. While this equation shows how investment policy is influenced by market developments, it does not provide a model of the underlying investment policy decisions, which are generally based on asset liability management studies. The results across pension fund size classes are quite similar.

We used three alternative approaches to check the robustness of our results.[13] First, we estimated all equations employing the alternative measure of excess equity returns based on market indices. Results were very close to the reported estimates based on self-reported returns, indicating that, on average, actual asset returns

[12] An alternative model, with first differences of *Policy* as the dependent variable, instead of gradual adjustment, leads to similar estimation results (not reported here).

[13] The tables of alternative estimates have not been reported here but are available upon request by the authors.

Table 6. Estimates of the Strategic Equity Allocation Model (1999:Q2–2006:Q4)

	All Funds		Small Funds	Medium-Sized Funds	Large Funds
	(1)	(2)	(3)	(4)	(5)
Equity Investment Policy $(t-1)$	0.972***	0.972***	0.970***	0.971***	0.978***
Yearly Excess Return MSCI	0.007***				
Yearly Excess Pension Funds' Equity Return		0.005***	0.005***	0.004***	0.005*
Size $(t-1)$	0.001***	0.001***	0.001	0.001	0.001
Intercept	0.001***	0.003***	0.002	0.004	−0.001
Number of Observations	16,156	11,273	5,425	4,488	1,360
R^2, Adjusted	0.950	0.954	0.941	0.952	0.955

Notes: ***, **, and * denote significance at the 1, 5, and 10 percent significance levels, respectively. The standard errors have been corrected for heteroskedasticity using the Huber-White sandwich estimators. Estimates for excess returns are based on data reported by pension funds.

followed the same pattern as index returns. Second, we also ran regressions for a balanced sample of a subset of 382 pension funds that reported at least seven years of data. The regression results were similar to those reported in tables 4–7 (table 7 appears in the appendix), suggesting that survivorship bias is not a significant issue. Third, we reestimated all regressions using fixed effects for pension funds and years. The Hausman test rejected random effects. The results are again fairly similar, except for table 6.[14] Overall, these results confirm that our outcomes are robust.

6. Conclusions

This article finds that stock market performance influences the asset allocation of pension funds in two ways. In the short term, the outperformance of equities over bonds and other investment categories automatically results in higher equity allocation (and vice versa), as pension funds do not continuously rebalance their asset allocation. Each quarter, pension funds rebalance, on average, around 39 percent of excess equity returns. The remaining 61 percent leads to higher or lower equity allocation as a result of free floating; these remaining excess equity returns are rebalanced in subsequent quarters. In the medium term, outperformance of equities induces pension funds to increase their strategic equity allocation (and vice versa). Overall, our estimates indicate that the investment policy of pension funds is partially driven by the (cyclical) performance of the stock market. Apparently, pension funds suffer from myopic investment behavior: they tend to base investment decisions on recent stock market performance rather than on long-term trends.

We also find that pension funds react asymmetrically to stock market shocks. Equity reallocation is higher after underperformance of equity investments than after outperformance. In particular, only 13 percent of positive excess equity returns is rebalanced, while 49 percent of negative shocks results in rebalancing. The former can be indicated as a “buy on the dip” strategy and the latter as a “the trend is your friend” approach. Thus, pension funds limit any

[14]In table 6, the coefficients’ levels of significance are substantially lower. Apparently, the pension funds’ fixed effects picked up a part of the variation in the explanatory variables.

decline in equity allocation in response to underperformance, but they allow higher exposures to equities when these outperform other investments. Apparently, equity portfolio managers are able to convince pension funds both to replenish their funds in bear markets (to profit from low asset prices) and to increase the equity allocation in bull markets (to take advantage of rising markets).

Large funds' investment behavior is different from that of small funds. They invest more in equity, and their equity allocation is affected much more strongly by actual equity returns. The latter implies that large funds rebalance less, possibly because managers enjoy more freedom in implementing market-timing strategies. We find asymmetric effects on excess equity returns, where the positive effects increase significantly with pension fund size. The coefficient of positive returns of the largest funds is, in fact, significantly above 1, reflecting "overshooting" of free floating, or "positive-feedback trading." A possible explanation is that managers of large funds have more freedom to respond to market developments and, particularly in bull markets, demonstrate great risk tolerance.

Appendix. Pension Funds' Equity Purchases and Sales

An alternative procedure to estimate rebalancing is to use the purchases and sales of equity investments as the dependent variable. Equation (7) estimates the impact of excess equity returns on net equity purchases or sales.

$$\begin{aligned} Equity\ purchases_{i,t} &= \alpha_4 + \beta_4\left(r^E_{i,t} - r^T_{i,t}\right) + \gamma_4 \Delta Policy_{i,t-1} \\ &\quad + \delta_4(Policy_{i,t-1} - w_{i,t-1}) + \lambda_4 Funding_{i,t-1} + \varepsilon_{i,t} \quad (7) \end{aligned}$$

$Equity\ purchases_{i,t}$ is defined as net equity purchases (+) or sales (−) of fund i at quarter t as a percentage of total equity. The explanatory variables are the same as before: $(r^E - r^T)$ measures excess stock market returns compared with other investment categories, $w_{i,t}$ is the percentage of pension fund equity investments, *Policy* is the strategic equity allocation, and *Funding* is the ratio of total investments and discounted pension liabilities. Additionally, we consider asymmetric effects of excess equity returns on equity transactions. We control for changes in the strategic equity allocation

Table 7. Estimates of the Equity Purchases and Sales Model (1999:Q2–2006:Q4)

	All Funds			Small Funds	Medium-Sized Funds	Large Funds
	(1)	(2)	(3)	(3)	(4)	(5)
Excess Equity Returns	−0.19***	−0.19***		−0.21***	−0.20***	−0.13***
Positive Excess Equity Returns			−0.07**			
Negative Excess Equity Returns			−0.23***			
Change in Strategic Equity Allocation ($t-1$)		0.10**	0.10***	0.10	0.11**	−0.03
Investment Gap ($t-1$)		0.34***	0.33***	0.40***	0.32***	0.24***
Funding Ratio ($t-1$)	−0.03***	−0.02***	−0.02***	−0.02***	−0.02***	−0.01
Intercept	0.05***	0.04***	0.04***	0.05***	0.04***	0.02***
Number of Observations	10,895	10,652	10,652	5,044	4,304	1,304
R^2, Adjusted	0.04	0.07	0.07	0.06	0.08	0.06

Notes: ***, **, and * denote significance at the 1, 5, and 10 percent significance levels, respectively. The standard errors have been corrected for heteroskedasticity, using the Huber-White sandwich estimators. Estimates for excess returns are based on data reported by pension funds.

($\Delta Policy$), for differences between the strategic equity allocation ($Policy - w$) and actual equity investments (the "investment gap"), and for the funding ratio, all lagged one quarter.

Table 7 presents evidence on rebalancing, as the percentage of equity portfolio purchases and sales is significantly affected by excess equity returns. Negative equity returns are the main force behind this phenomenon (see column 3). The investment gap is also a significant driver of equity portfolio sales and purchases. Although the rebalancing and investment-gap effects are significant, only a tiny portion of the variation in equity portfolio sales and purchases is explained by our model (see adjusted R^2).

Turning to the size class estimates, we find less rebalancing behavior of the larger funds compared with small funds. This is further emphasized by the observation that larger funds also react less than small funds to changes in the policy and investment gap.

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The Role of Asset Prices in Best-Practice Monetary Policy*

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I study the role of asset prices in the conduct of monetary policy under the commitment equilibrium. The findings lend support to the lean-against-the-wind strategy in that it is optimal for the central bank to set interest rates to respond to asset-price movements. The gain from responding to asset prices comes from the fact that asset-price movements can provide a signal about the development in the state of the economy. The paper also suggests that prior to and during the subprime mortgage crisis of 2007, it would have been optimal for the Federal Reserve to increase the weight of asset prices in its rate-setting decision.

JEL Codes: E44, E52.

1. Introduction

The issue of asset prices in the conduct of monetary policy has come back right to the fore of the debate following the subprime mortgage crisis of 2007. After the sustained increase in house prices between 2001 and 2005, the booming housing market halted abruptly in the late summer of 2005, which caused house prices to be flat for the rest of 2005 and throughout 2006.[1] At the beginning of 2007, house prices

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[1]During 2001–05, the average year-on-year growth rate of the S&P/Case-Shiller Home Price Index was 12.4 percent, with the number of existing homes sold growing at an annual rate of 6.2 percent. The annualized number of existing homes sold peaked at 6.3 million in September 2005. Subsequently, the number of existing homes sold declined at an annual rate of 8.7 percent.

started to decline, and the downward movement in house prices continued during 2007–08.[2] This led to a sharp rise in the default rate, especially on subprime mortgage loans made to high-risk borrowers. Mortgage lenders who underwrote such loans and financial institutions who bought collateralized debt obligations (CDOs) backed by mortgage payments in turn suffered huge losses. In response to the crisis, the Federal Reserve lowered the target for the federal funds rate 50 basis points to 4.75 percent in September 2007, after maintaining the target rate at 5.25 percent for fifteen months. Given that the subprime mortgage crisis might have repercussions for other sectors and might cause the economy to slip into a recession, the Federal Reserve continued to lower the target federal funds rate in the two remaining Federal Open Market Committee (FOMC) meetings in 2007.

This raises a question about how the central bank should conduct monetary policy amid asset-price booms and busts. One prominent approach suggested by several authors is for the central bank to respond to asset-price movements only insofar as the latter affect the forecast of inflation.[3] Under this notion, an appropriate monetary policy strategy is to set short-term interest rates to respond strongly to inflation, and there is little gain from responding directly to asset prices.[4] This also implies that the central bank should not attempt to strike down an asset-price boom. Instead, the central bank should follow the "mop-up-after" strategy by being alert and easing the monetary policy stance to alleviate the adverse effect from a sharp fall in asset prices.

An alternative approach, proposed by the so-called lean-against-the-wind camp, is that the central bank can improve macroeconomic

[2]From the second half of 2006, house prices, as measured by the S&P/Case-Shiller Index, were flat, growing at 4.5 percent a year. However, since January 2007, the S&P/Case-Shiller Index has declined in every month. The median home sale price collected by the National Association of Realtors, another measure of house prices, peaked at $230,900 in June 2006 and has declined in every month since at an annual rate of 2.5 percent.

[3]See Bernanke and Gertler (1999, 2001), Gilchrist and Leahy (2002), Tetlow (2005), Gilchrist and Saito (2006), and Faia and Monacelli (2007). This idea is also consistent with what was proposed by Alan Greenspan. See Greenspan (2002, 2005).

[4]To respond *strongly* to inflation means that the extent to which the central bank raises the nominal interest rate is much larger than the increase in inflation.

performance by setting short-term interest rates to respond to asset-price movements. This implies that the central bank should raise short-term interest rates as asset prices go up, even though other target variables, such as inflation forecasts and employment, are roughly on target.[5]

This paper examines how the central bank should take into account asset-price movements in its interest-rate-setting process. What distinguishes this paper from previous studies is that this paper examines the role of asset prices in the conduct of monetary policy in the commitment equilibrium.[6] Under the goal of maintaining price stability and full employment, optimal policy under commitment yields the best possible outcome that the central bank is capable of implementing. The result in this paper thus provides an implication on which strategy, mopping up after or leaning against the wind, is optimal policy.

The present paper finds that the leaning-against-the-wind strategy is optimal. In particular, from the standpoint of a central bank whose objective is to maintain price stability and full employment, it is optimal to set interest rates to respond to asset-price movements. The reason, according to the analysis in this paper, is that asset-price movements can provide signals about the development in the state of the economy that the central bank cannot perfectly observe. The results in this paper also suggest that before and during the subprime mortgage crisis of 2007, in which it may have been difficult for the Federal Reserve to perfectly verify creditworthiness and risk premiums of U.S. households, the Federal Reserve should have paid even more attention to asset-price movements. The usefulness of asset prices in the rate-setting process nonetheless depends on the degree to which the central bank can verify the nature of asset-price misalignments.

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[5]See, for instance, Cecchetti et al. (2000) and Bordo and Jeanne (2002a, 2002b).

[6]The earlier literature conducts the analysis by relying on some preselected sets of Taylor-type interest rate rules. Thus, the earlier literature is silent on what is the optimal strategy amid asset-price booms and busts. Bordo and Jeanne (2002a, 2002b) do not conduct their analysis on standard New Keynesian-type DSGE models. Rather, they conduct their analysis in a stylized model with a finite number of periods and thus do not derive the rational-expectations equilibrium.

The remainder of the paper proceeds in the following manner. Section 2 sets up the model used for the analysis. Section 3 presents the policy problem of a central bank who can commit, and provides an algorithm for computing optimal policy under commitment. Section 4 considers whether it is optimal for the central bank to respond to asset prices in a hypothetical world in which the central bank can perfectly observe the state of the economy. Section 5 considers more realistic scenarios in which the assumption of full information is relaxed. Under the partial-information case, the central bank solves an optimal filtering problem, using asset prices as an indicator. Section 6 examines whether the main findings in this paper depend on some important assumptions. Section 7 concludes.

2. The Model Economy

The model used in the analysis is the one presented in Gilchrist and Saito (2006) (henceforth, GS). The GS model is essentially a standard New Keynesian model augmented to include credit-market frictions through the financial accelerator mechanism described in Bernanke, Gertler, and Gilchrist (1999) (henceforth, BGG). The model consists of six sectors: households, entrepreneurs, retailers, capital producers, the government, and the central bank. Households consume, hold money, save in one-period riskless bonds, and supply labor to entrepreneurs. Entrepreneurs manage the production of wholesale goods, which requires capital constructed by capital producers and labor supplied by both households and entrepreneurs. Entrepreneurs purchase capital and finance the expenditures of capital with their net worth and debt. Entrepreneurs sell wholesale goods to monopolistically competitive retailers who differentiate the product slightly at zero resource cost. Each retailer then sets its price and sells its differentiated product to households, capital producers, entrepreneurs, and the government.

Rather than work through the details of the derivation, which are readily available in GS, I instead directly introduce the log-linearized version of the aggregate relationships of the model.

Table 1 provides a summary of the variables in the model. Throughout, steady-state levels of the variables are in lower case without time subscripts while log-deviations from the steady-state

Table 1. Summary of the Model Variables

Variable	Explanation
c_t	Consumption
z_t	Productivity Growth
i_t	Nominal Interest Rate
π_t	Inflation
r_t^k	Real Rate of Return on Capital
y_t	Output
k_{t+1}	Capital at the End of Period t
mc_t	Real Marginal Cost
q_t	Price of Capital
s_t	External Finance Premium
n_{t+1}	Net Worth at the End of Period t
inv_t	Investment
h_t	Labor Supply
ε_t	Transitory Shock to Productivity
d_t	Persistent Component of Productivity
υ_t	Persistent Shock to Productivity
$\widehat{y}_t$	Output Gap
r_t^*	Natural Interest Rate

are in lower case with time subscripts. The corresponding hypothetical levels of the variables in the frictionless economy are denoted by an asterisk. Greek letters and lowercase Roman letters without subscripts denote fixed parameters. Table 2 provides a summary of the parameters as well as their baseline calibration.

The first equation is the log-linearized version of the national income identity:

$$y_t = \frac{c}{y} c_t + \frac{\mathrm{inv}}{y} \mathrm{inv}_t. \tag{1}$$

Note that in the baseline calibration of the GS model, entrepreneurs' consumption and government spending are normalized to zero. Model simulations conducted under the original BGG framework imply that these simplifications are reasonable.

Households' consumption is determined by a standard Euler equation summarizing households' optimal consumption-savings allocation:

Table 2. Baseline Calibration of the Model Parameters and the Steady-State Level of Some Key Variables

Parameter	Explanation	Baseline Calibration
β	Discount Factor	0.984
α	Labor Share	2/3
γ	Inverse of Labor Supply Elasticity	0.8
δ	Depreciation Rate	0.025
η_k	Elasticity of Asset Prices	0.25
$\varepsilon/(\varepsilon-1)$	Steady-State Markup	1.1
υ	Calvo Parameter	0.75
$k/n-1$	Steady-State Leverage Ratio	0.8
χ	Elasticity of the Finance Premium	0.05
μ	Mean Technology Growth Rate	0.00427
σ_ε	Standard Deviation of the Transitory Shock	0.01×100
σ_υ	Standard Deviation of the Persistent Shock	0.001×100
ρ_d	AR(1) Coefficient of the Persistent Shock	0.95

$$-c_t = -\mathrm{E}_t c_{t+1} - \mathrm{E}_t z_{t+1} + i_t - \mathrm{E}_t \pi_{t+1}. \quad (2)$$

z_t, the growth of productivity, enters the Euler equation, as well as several other equations in the model, because the levels of consumption, investment, output, capital stock, and net worth are normalized by the level of technology, in order to make these real quantities stationary.

Households also make a decision on labor supply. Labor demand, on the other hand, is derived from entrepreneurs' profit maximization problem. In an equilibrium, labor supply equals labor demand. Using the labor-demand condition to eliminate wages from the labor-supply equation yields the following labor-market equilibrium condition:

$$y_t + \mathrm{mc}_t - c_t = (1+\gamma)h_t. \quad (3)$$

mc_t enters (3) because we use the definition of mc_t, $\mathrm{mc}_t = p_{w,t} - p_t$, to eliminate $p_{w,t} - p_t$, where $p_{w,t}$ is the wholesale price and p_t is the price level of the economy. Equation (3) thus is the equation that defines mc_t in the system.

On the production side, entrepreneurs have access to a Cobb-Douglas technology:

$$y_t = \alpha h_t + (1-\alpha)k_t - (1-\alpha)z_t. \quad (4)$$

Capital k_t is purchased by the entrepreneurs at the end of period $t-1$. The expected real rate of return on capital, $\mathrm{E}_t r^k_{t+1}$, is given by

$$\mathrm{E}_t r^k_{t+1} = \frac{\mathrm{mc}(1-\alpha)\frac{y}{k}Z}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}(\mathrm{E}_t y_{t+1} - k_{t+1} + \mathrm{E}_t z_{t+1} + \mathrm{E}_t \mathrm{mc}_{t+1}) + \frac{1-\delta}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}\mathrm{E}_t q_{t+1} - q_t. \quad (5)$$

Intuitively, the expected real rate of return on capital depends on the marginal profit from the production of wholesale goods, which (log-linearized) is given by

$$\frac{\mathrm{mc}(1-\alpha)\frac{y}{k}Z}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}(\mathrm{E}_t p_{w,t+1} - \mathrm{E}_t p_{t+1} + \mathrm{E}_t y_{t+1} - k_{t+1}).$$

$\mathrm{E}_t y_{t+1} - k_{t+1}$ is derived from log-linearizing the marginal product of capital. Substituting the real marginal cost (for the retailers), $\mathrm{mc}_t = p_{w,t} - p_t$, we derive the first part of the right-hand side of (5). The second part, $\frac{1-\delta}{\mathrm{mc}(1-\alpha)\frac{y}{k}Z+(1-\delta)}\mathrm{E}_t q_{t+1} - q_t$, is the capital gain. Summing the marginal profit and the capital gain, we derive the real rate of return on capital.

To finance their capital expenditures, the entrepreneurs employ internal funds, net worth, but also need to acquire loans from financial intermediaries. In the presence of credit-market frictions, the financial intermediaries can verify the return on the entrepreneurial investment only through the payment of a monitoring cost. The financial intermediaries and the entrepreneurs design loan contracts to minimize the expected agency cost. The nature of the contracts is that the entrepreneurs need to pay a premium above the riskless rate, which in this model is the opportunity cost for the financial intermediaries. The external finance premium in turn depends on the financial position of the entrepreneurs. In particular, the external finance premium increases when a smaller fraction of the capital expenditures are financed by the entrepreneurs' net worth:

$$s_t = \chi(q_t + k_{t+1} - n_{t+1}). \quad (6)$$

In a competitive financial market, the expected cost of borrowing is equated to the expected return on capital:

$$\mathrm{E}_t r_{t+1}^k = i_t - \mathrm{E}_t \pi_{t+1} + s_t, \tag{7}$$

where $i_t - \mathrm{E}_t \pi_{t+1}$ is the (real) riskless rate.

The rest of the capital expenditures are financed by entrepreneurial net worth, which is determined by

$$n_{t+1} = \frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right) \mathrm{E}_{t-1} r_t^k + n_t - z_t.$$

That is, the aggregate net worth of the entrepreneurs at the end of period t is the sum of the net worth from the previous period, n_t, and $\frac{k}{n} r_t^k - (\frac{k}{n} - 1)\mathrm{E}_{t-1} r_t^k$, the operating profit of the entrepreneurs earned during period t. $\frac{k}{n} r_t^k$ is the (log-linearized) realized return on investment. $(\frac{k}{n} - 1)\mathrm{E}_{t-1} r_t^k$ is the (log-linearized) entrepreneurs' marginal cost of external funds that is predetermined in period t by the financial intermediaries. Using the definition of the external finance premium, $\mathrm{E}_{t-1} r_t^k = s_{t-1} + i_t - \mathrm{E}_{t-1}\pi_t$, we have

$$n_{t+1} = \frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right)(s_{t-1} + i_t - \mathrm{E}_{t-1}\pi_t) + n_t - z_t. \tag{8}$$

The entrepreneurs purchase capital from capital producers who combine investment and depreciated capital stock. This activity entails physical adjustment costs, with the corresponding CRS production. The aggregate capital accumulation equation is thus given by

$$k_{t+1} = \frac{(1-\delta)}{Z}(k_t - z_t) + \left(1 - \frac{1-\delta}{Z}\right)\mathrm{inv}_t. \tag{9}$$

Capital producers maximize profit subject to the adjustment cost, yielding the following first-order condition:

$$q_t = \eta_k(\mathrm{inv}_t - k_t + z_t). \tag{10}$$

Equation (10) can be interpreted as an equilibrium condition for the investment-good market. That is, the demand for investment from entrepreneurs equals the investment goods supplied by capital producers. This determines the price of capital, which in this model is interpretable as asset prices. Equation (10) implies that investment increases as asset prices rise.

The retailers set prices in a staggered fashion, as in Calvo (1983). This gives rise to a standard Phillips curve:

$$\pi_t = \kappa \mathrm{mc}_t + \beta \mathrm{E}_t \pi_{t+1}. \tag{11}$$

It is practical to use (11) to write the dynamics of net worth as

$$n_{t+1} = \frac{k}{n} r_t^k - \left(\frac{k}{n} - 1\right)\left(s_{t-1} + i_t - \frac{\pi_{t-1}}{\beta} + \frac{\kappa}{\beta}\mathrm{mc}_{t-1}\right) + n_t - z_t. \tag{12}$$

The growth of productivity has both transitory and persistent components:

$$z_t = d_t + \varepsilon_t. \tag{13}$$

The persistent component follows an AR(1) process:

$$d_t = p_d d_{t-1} + \upsilon_t, \tag{14}$$

where shocks to the transitory and persistent components are

$$\varepsilon_t \sim i.i.d.N(0, \sigma_\varepsilon^2)$$

and

$$\upsilon_t \sim i.i.d.N(0, \sigma_\upsilon^2).$$

Finally, since one of the central bank's target variables is the output gap, which is the deviation of output from its hypothetical level in the frictionless economy, we also have the following set of equations defining the frictionless economy:

$$y_t^* - c_t^* = (1+\gamma) h_t^* \tag{15}$$

$$y_t^* = \alpha h_t^* + (1-\alpha) k_t^* - (1-\alpha) z_t \tag{16}$$

$$y_t^* = \frac{c}{y} c_t^* + \frac{\mathrm{inv}}{y} \mathrm{inv}_t^* \tag{17}$$

$$k^*_{t+1} = \frac{1-\delta}{Z}(k^*_t - z_t) + (1 - \frac{1-\delta}{Z})\text{inv}^*_t \tag{18}$$

$$q^*_t = \eta_k(\text{inv}^*_t - k^*_t + z_t) \tag{19}$$

$$\begin{aligned} r^*_t = & \frac{\text{mc}(1-\alpha)\frac{y}{k}Z}{\text{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}(\text{E}_t y^*_{t+1} - k^*_{t+1} + \text{E}_t z_{t+1}) \\ & + \frac{1-\delta}{\text{mc}(1-\alpha)\frac{y}{k}Z + (1-\delta)}\text{E}_t q^*_{t+1} - q^*_t \end{aligned} \tag{20}$$

$$-c^*_t = -\text{E}_t c^*_{t+1} - \text{E}_t z_{t+1} + r^*_t \tag{21}$$

$$\widehat{y}_t = y_t - y^*_t. \tag{22}$$

Thus, I define the frictionless variables conditional on the hypothetical level of capital stock that exists when the economy has been under flexible prices and without credit-market frictions, as in Neiss and Nelson (2003). I also conducted the analysis in this paper by defining the frictionless economy conditional on the actual level of capital stock, as in Woodford (2003). All of the conclusions in this paper remain valid under the Woodford approach. I follow Neiss and Nelson because this approach allows me to illustrate my results in a particularly sharp way.[7]

For ease of presentation, write the model economy in the state-space format, as in Svensson (2006):

$$\begin{bmatrix} X_{t+1} \\ Hx_{t+1|t} \end{bmatrix} = A \begin{bmatrix} X_t \\ x_t \end{bmatrix} + Bi_t + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1}, \tag{23}$$

[7]Like Gilchrist and Saito (2006), in the frictionless economy, there are no nominal rigidities and credit-market frictions. The reason that I define the frictionless economy as the flex-price economy in the absence of credit-market frictions as opposed to in the presence of credit-market frictions is because it can be argued that a goal of the central bank is to lead the economy as close as possible to the "distortion-free" state. In this model economy, credit-market frictions are distortions in the form of asymmetric information in financial markets that in turn gives rise to fluctuations in the external finance premium. As will be shown later, the central bank can in fact stabilize the external finance premium. At the micro level, unlike the distortions arising from monopolistic competition that are beyond central banks' authority to deal with, most central banks, including the Federal Reserve, are capable of dealing with the distortions in financial markets. As pointed out by Bernanke (2002), "The Fed has been entrusted with the responsibility of helping to ensure the stability of the financial system . . . by supporting such objectives as more transparent accounting and disclosure practice and working to improve the financial literacy and competence of investors."

where X_t is an n_X-vector of predetermined variables, x_t is an n_x-vector of non-predetermined variables, i_t is an n_i-vector of instruments, and ε_t is an n_ε-vector of exogenous zero-mean i.i.d. shocks. The matrices A, B, C, and H are of dimension $(n_X+n_x)\times(n_X+n_x)$, $(n_X+n_x)\times n_i$, $n_X\times n_\varepsilon$, and $n_x\times n_x$, respectively. For any vector z_t, $z_{t+1|t}$ denotes the rational expectations $\mathrm{E}_t z_{t+1}$.

It is practical to partition A and B conformably with X_t and x_t,

$$A \equiv \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}, \qquad B \equiv \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}.$$

Under this format, the system includes nine predetermined variables, twenty non-predetermined variables, two shocks, and one instrument. Appendix 1 includes the detail on how to present the GS model into the canonical format (23).

3. Optimal Policy under Commitment

Let the intertemporal loss function in period 0 be

$$\mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t L_t, \tag{24}$$

where

$$L_t = \frac{1}{2}[\pi_t^2 + \lambda \widehat{y}_t^2 + \nu(i_t - i_{t-1})^2]. \tag{25}$$

This is a flexible inflation-targeting loss function where $\delta(0 < \delta < 1)$ denotes the constant discount factor, $\lambda > 0$ a relative weight on output-gap variability, and $\nu > 0$ a relative weight on interest rate smoothing.

Consider minimizing (24) under commitment once and for all in period $t = 0$, subject to (23) for $t \geq 0$ and $X_0 = \overline{X}_0$ where $\overline{X}_0$ is given. The Lagrangian of the dynamic optimization can be written as

$$\mathcal{L}_0 = \mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t \begin{bmatrix} L_t + \Xi_t'(Hx_{t+1} - A_{21}X_t - A_{22}x_t - B_2 i_t) \\ +\xi_{t+1}'(X_{t+1} - A_{11}X_t - A_{12}x_t - B_1 i_t - C\varepsilon_{t+1}) \end{bmatrix}$$
$$+ \frac{1-\delta}{\delta}\xi_0'(X_0 - \overline{X}_0), \tag{26}$$

where ξ_{t+1} and Ξ_t are vectors of n_X and n_x Lagrange multipliers of the upper and lower blocks, respectively, of the canonical system (23).

Following Svensson (2006), I solve this problem by the recursive saddlepoint method of Marcet and Marimon (1998). Appendix 2 provides an algorithm on how to solve this problem using the recursive saddlepoint method. It can be shown that the solution, or the commitment equilibrium, takes the form of the following policy function and law of motion of the state of the economy:

$$\begin{bmatrix} x_t \\ i_t \\ \gamma_t \end{bmatrix} = F \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix}$$

$$\begin{bmatrix} X_{t+1} \\ \Xi_t \end{bmatrix} = M \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix} + \begin{bmatrix} C \\ 0 \end{bmatrix} \varepsilon_{t+1}. \tag{27}$$

Thus, it follows that the instruments and the non-predetermined variables depend on the state of the economy according to

$$i_t = F_i \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix} \tag{28}$$

$$x_t = F_x \begin{bmatrix} X_t \\ \Xi_{t-1} \end{bmatrix}, \tag{29}$$

where F_i and F_x are appropriate rows in F.

4. Should the Central Bank Respond to Asset Prices? The Full-Information Case

As shown in (28), the reaction function of the central bank can be described as

$$i_t = F_i \widetilde{X}_t. \tag{30}$$

Since q_t, the asset price, is non-predetermined, under the commitment equilibrium, q_t satisfies

$$q_t = F_q \widetilde{X}_t,$$

where F_q is an appropriate row vector in F_x.

It follows that $q_t - F_q\widetilde{X}_t = 0$ and thus

$$i_t = F_i\widetilde{X}_t + \theta(q_t - F_q\widetilde{X}_t), \quad \text{for any } \theta.$$

Or rearranging further,

$$i_t = (F_i - \theta F_q)\widetilde{X}_t + \theta q_t. \tag{31}$$

Thus, one can choose any feedback coefficient on q_t and (31) is still satisfied. In other words, in the commitment equilibrium, it is irrelevant to discuss whether the interest rate instrument should be set to respond directly to asset prices. The reason is that asset prices are fully determined by the state of the economy.[8] Hence, if the central bank can perfectly observe the state of the economy and has already set the interest rate instrument to respond to the state of the economy as in (30), there will be no additional gain from responding to asset prices directly. Specifically, in an environment with full information in which the central bank can perfectly observe the state of the economy, all of the information necessary for the monetary policymaking process has already been contained in the state of the economy. Movements in asset prices do not reveal any extra information.

Table 3 reports the coefficients of (30). These are the feedback coefficients on the state of the economy, as represented by the predetermined variables X_t as well as the Lagrange multipliers on the non-predetermined block of (23), Ξ_{t-1}.

The interpretation of the predetermined variables X_t is straightforward. The Lagrange multipliers can be interpreted as "promises" of the central bank to deliver the level of non-predetermined variables that it has committed from the previous period. To derive the promise for a specific variable, the promise terms in the dual-period loss function (38) need to be rearranged so that all terms with the variable in question are grouped together.[9] For instance, the promise on the level of inflation will be $-\frac{\Xi_{1t-1}}{\beta} + \frac{\Xi_{9t-1}}{\beta} + \Xi_{3t-1}$. $-\frac{\Xi_{1t-1}}{\beta} + \frac{\Xi_{9t-1}}{\beta} + \Xi_{3t-1} > 0$, for instance, implies that the central

[8]In this framework, the state of the economy consists of the predetermined variables and the Lagrange multipliers of the non-predetermined equations.

[9]This is because most non-predetermined equations have expectations terms on more than one variable.

Table 3. The Feedback Coefficients of the Reaction Function

Variables	Optimal Feedback Coefficients
k_t	−0.0997
s_{t-1}	0
n_t	0
π_{t-1}	0
ε_t	0.0099
d_t	0.4196
k_t^*	0.0898
i_{t-1}	0.1165
mc_{t-1}	0
Ξ_{1t-1}	0.3640
Ξ_{2t-1}	0
Ξ_{3t-1}	−0.1125
Ξ_{4t-1}	−0.0893
Ξ_{5t-1}	0
Ξ_{6t-1}	0
Ξ_{7t-1}	0
Ξ_{8t-1}	0
Ξ_{9t-1}	0.3155
Ξ_{10t-1}	0
Ξ_{11t-1}	0
Ξ_{12t-1}	0
Ξ_{13t-1}	0
Ξ_{14t-1}	0
Ξ_{15t-1}	0
Ξ_{16t-1}	0
Ξ_{17t-1}	0
Ξ_{18t-1}	0
Ξ_{19t-1}	0
Ξ_{20t-1}	0

bank made a promise in the previous period that today it will deliver an inflation rate lower than if it did not make the promise, no matter how the state of the economy is realized today. This is a hallmark of optimal policy under commitment in the sense that promises made in the past do constrain current policy in an optimal way.

Table 3 provides another interesting implication. As noted, in the full-information scenario in which the central bank can perfectly observe the state of the economy, there is no additional gain from responding to today's asset prices. However, it is possible to be optimal for the central bank to respond to *last period's* asset prices. The reason is that s_{t-1}, the external finance premium in the last period, is a predetermined variable. Last period's external finance premium is predetermined because it is a factor that determines *today*'s borrowing cost. Under the Townsend (1979)-style optimal loan contract, the borrowing cost in period t is determined in period $t-1$, whereby the lenders formed expectations on the state of the economy and, in particular, the possibility of defaults in period t. The lenders then marked up the borrowing cost over their opportunity cost to compensate for the default risk. Thus, the borrowing cost in the current period is in fact a predetermined variable that characterizes the state of the economy. s_{t-1} then enters X_t because it is a factor that determines the borrowing cost, $\mathrm{E}_{t-1}r_t^k$, in period t. That is why mc_{t-1} and π_{t-1}, the other factors that determine $\mathrm{E}_{t-1}r_t^k$, also enter X_t.

In this way, since movements in asset prices can affect the value of capital owned by entrepreneurs and thereby their net worth, which is the reason why the external finance premium can be affected by asset prices, it may be optimal for the central bank to respond to the lagged asset prices if there is a rationale for the bank to respond to last period's external finance premium.

Table 3, however, suggests that it may not be optimal for the central bank to respond to last period's external finance premium and thereby to the lagged asset prices. More precisely, the table implies that it is optimal for the central bank *not* to respond to the cost of borrowing, as evident from the fact that the feedback coefficients on all other factors that determine the borrowing cost, namely mc_{t-1} and π_{t-1}, are also zero.

Intuitively, the cost of borrowing for period t is determined solely by the expectations, which were formed in period $t-1$, on the state of the economy in period t. However, when the central bank is setting the interest rate instrument in period t, it has already had a chance to observe the realized state of the economy, including especially the productivity shock, in that period. Thus, the central bank can simply utilize the information that has already been observed in the period. The expectations on the state of the economy, which has already been realized and is fully observable, provide no additional useful information. In other words, it is inefficient for the central bank to respond to a (past) prediction of the outcome of an event when the outcome has already been known to the central bank.

5. Should the Central Bank Respond to Asset Prices? The Partial-Information Case

The analysis in the previous section provides a benchmark scenario in which policy should be conducted when the state of the economy is perfectly observable. This is, however, a hypothetical setup that is unlikely to be true in practice. In the real world, central banks will not be able to observe most economic variables, or aggregate economic activities, directly. In the policymaking process, central banks must rely on economic indicators that are constructed to reflect aggregate economic activities. Economic indicators, however, are not perfect measures of aggregate economic activities, since each economic indicator arguably is subject to some forms of errors.[10] This implies that real-world central banks are required to make interest rate decisions while facing imperfect knowledge about the state of the economy.

Thus, consider a scenario in which the state of the economy is imperfectly observable, as analyzed in Svensson and Woodford (2003). That is, some or all of the elements in X_t, x_t, and Ξ_{t-1} are assumed to be unobservable or partially observable. Furthermore, information is assumed to be symmetric in the sense that the private agents and the central bank have the same information set.

Let the vector of n_z observable variables, or indicators, Z_t, be given by

[10] Evidence has found that most economic indicators are subject to imperfection in the form of measurement errors and data revisions. Most notably among others, Orphanides (2001, 2003) has pointed out that in reality central banks need to make a decision based on error-prone data that usually are substantially revised even a year after their releases. For instance, the 1996 Boskin Commission report estimated that the U.S. CPI was upward biased by 1.1 percent per year. Most recently, following the release of the U.S. second-quarter GDP in 2006 were downward revisions to real growth in each of the past three years. Goldman Sachs calculated that the average adjustment to U.S. quarterly GDP growth between 1999 and 2004 was –0.4 percentage point.

$$Z_t = \widetilde{D}\begin{bmatrix} X_t \\ x_t \end{bmatrix} + v_t, \tag{32}$$

where v_t, the vector of noise, is i.i.d. with mean zero and covariance matrix Σ_{vv}. Other setups remain the same as those in section 3.

Under this setting, Svensson and Woodford (2003) show that in the commitment equilibrium, certainty equivalence holds. That is, the optimal policy is the same as if the state of the economy were fully observable except that one responds to an efficient estimate of the state vector rather than to its actual value. Furthermore, a separation principle applies, according to which the selection of the optimal policy and the estimation of the current state of the economy can be treated as separate problems.

It can be shown that in the partial-information economy the central bank can set the interest rate instrument to respond to an infinite sum of current and lagged indicators, according to the following reaction function:

$$i_t = \widetilde{F}\left(\sum_{\tau=0}^{\infty} Q_\tau K Z_{t-\tau}\right) + \Phi\left(\sum_{\tau=0}^{\infty}\Sigma^\tau S \sum_{s=0}^{\infty} Q_s K Z_{t-1-\tau-s}\right). \tag{33}$$

Appendix 3 provides an algorithm for computing Q, K, S, and Σ.

5.1 Optimal Weights on Indicators under Partial Information

The effect of incomplete information on the role of asset prices can be best shown by a quantitative exercise. In particular, I will derive in this section the optimal weights, or the optimal feedback coefficients, on current and lagged indicators as in (33) under the base-case calibration of the GS model, for a given set of indicators and a calibrated covariance Σ_{vv}.

Consider a scenario in which the central bank employs the following set of indicators:[11]

[11] My conclusions, however, do not depend on what variables are included in the indicator set. I examine the indicator set (34) as my baseline analysis because this setup is fairly general but at the same time allows me to get my message across in a sharp way. The results on other sets of indicators are available upon request.

$$Z_t = \begin{Bmatrix} k_t, n_t, \varepsilon_t, d_t, k_t^*, z_t, \pi_t, r_t^k, y_t, \text{mc}_t, q_t, \text{inv}_t, \\ h_t, k_{t+1}, n_{t+1}, y_t^*, h_t^*, c_t^*, k_{t+1}^*, \text{inv}_t^*, q_t^*, r_t^* \end{Bmatrix}. \quad (34)$$

Thus, the central bank employs all variables that are necessary to compute every key aspect of the economy. Given that c_t can be inferred from y_t and inv_t, including c_t is redundant and thus it is excluded from the set. The same reason goes for s_t and $\widehat{y}_t$ since s_t can be inferred from r_t^k and r_t, and $\widehat{y}_t$ can be inferred from y_t and y_t^*. From a preliminary analysis, c_t, s_t, and $\widehat{y}_t$ receive zero weights when they are included in the indicator set.

It should be noted that the central bank cannot perfectly observe the fundamental values of assets. What the central bank can observe are the market values of assets, which are readily available from the financial markets. Thus, q_t in the indicator set denotes market prices of assets. The movements in q_t capture the movements in the fundamental values of assets as well as in the asset-price misalignments or bubbles.

In the base-case analysis, the variance of productivity growth and all of the hypothetical frictionless variables, or *noisy indicators*, is calibrated to 0.1.[12] This is consistent with the fact that, in general, real-world central banks cannot perfectly verify exogenous disturbances and hypothetical frictionless variables, such as potential output. Nonetheless, central banks often include their estimates of these variables in their monetary policymaking process.[13]

The variance of all other indicators, or *reliable indicators*, is taken to be 0.0001, or $\frac{1}{1000}$ of that of the noisy indicators. That is, these indicators are quite accurately measured but still contain some unavoidable noise. This setup is intended to simulate the real-world

[12] The main findings here do not depend on the calibration of the variance of noise to indicators. Section 6 provides a robustness test on whether the results in this paper remain valid for different assumptions on the variance.

[13] Orphanides and van Norden (2002), for example, point out that although it is necessary to estimate potential output and thus the output gap for the policymaking process, the reliability of such estimates in real time tends to be quite low. The August 18, 2006 issue of *Financial Times* also reports that following a series of data revisions, economists may have overestimated the growth rate of potential output by as much as 60 basis points.

situation in which most economic data, including those used as the reliable indicators in (34), are subject to errors.[14]

5.2 Leaning against the Wind by Employing Asset Prices as an Indicator

Table 4 reports the optimal feedback coefficients on the current values of the indicators in (34) and those on their lags up to two periods, under the base-case calibration in which the variance of the noise to the noisy indicators is 0.1 and that to the reliable indicators is 0.0001.[15]

As evident from the table, when the central bank cannot observe the state of the economy perfectly, the feedback coefficients on asset prices become strictly different from zero. In this sense, table 4 implies that when the central bank cannot perfectly verify the state of the economy, the central bank should take asset prices into account in determining the path of the interest rate instrument. Row 11 of the table also implies that asset prices in the current period are relatively more informative than lagged asset prices.

As a basis for comparison, table 5 provides the optimal feedback coefficients under a hypothetical scenario in which the variance of the noise to the noisy indicators, including shocks and frictionless variables, is assumed to be equal to that of the reliable indicators, or equal to 0.0001.

Tables 4 and 5 show that when it becomes more uncertain to verify the state of the economy, particularly productivity growth and the frictionless variables, it is optimal for the central bank to utilize more information revealed by the more reliable indicators, including asset prices. In particular, the weights given to asset prices rise further, compared with the scenario when all indicators are relatively accurate.

[14]Economic indicators, by default, should be subject to at least some small amounts of errors. The reason is that most economic indicators are constructed from survey data which, by construction, are subject to sampling errors. Those indicators taken from the national income account or the balance of payments are also error prone, in the form of statistical discrepancies due to data collection, data entry, and unreported activities. Finally, even asset prices observed in the markets—such as equity prices, house prices, and foreign exchange rates—are considered noisy if what central banks really need to measure are the fundamental values of these assets.

[15]Note that in the table $y\mathrm{E}-0Z$ denotes $y \cdot 10^{-Z}$.

Table 4. Optimal Feedback Coefficients on a Distributed Lag of the Indicators when the Variance of the Noisy Indicator is 0.1

Indicator	Current Period	One-Period Lag	Two-Period Lag
k_t	4.806E-03	2.485E-03	1.316E-03
n_t	4.458E-03	2.305E-03	1.221E-03
ε_t	−6.122E-02	−3.449E-02	−1.967E-02
d_t	6.126E-02	3.450E-02	1.967E-02
k_t^*	5.801E-04	1.196E-03	1.075E-03
z_t	3.040E-05	7.497E-06	4.625E-07
π_t	1.696E-03	3.320E-04	−5.654E-05
r_t^k	1.332E-03	3.230E-04	1.491E-05
y_t	−2.129E-03	−4.169E-04	7.100E-05
mc_t	1.942E-02	3.802E-03	−6.474E-04
q_t	1.837E-03	3.596E-04	−6.124E-05
inv_t	−1.825E-02	−3.574E-03	6.085E-04
h_t	9.604E-03	1.881E-03	−3.203E-04
k_{t+1}	−2.538E-02	−4.970E-03	8.463E-04
n_{t+1}	−2.355E-02	−4.610E-03	7.851E-04
y_t^*	2.164E-04	4.680E-04	4.229E-04
h_t^*	4.979E-05	1.077E-04	9.729E-05
c_t^*	1.268E-04	2.742E-04	2.478E-04
k_{t+1}^*	5.598E-04	1.211E-03	1.094E-03
inv_t^*	8.950E-04	1.935E-03	1.749E-03
q_t^*	8.631E-05	1.867E-04	1.687E-04
r_t^*	−1.268E-04	−2.742E-04	−2.478E-04

These results suggest that asset prices can provide information regarding the developments in the state of the economy. The more uncertainty surrounding the true state of the economy, the greater the role of asset prices should be in the rate-setting procedure. This is a reason why it is desirable for the central bank to respond to asset prices.

The present paper thus lends support to the lean-against-the-wind camp that the central bank should respond to movements in the market values of assets. According to the analysis in this paper, this is an optimal strategy that will prevent asset prices from persistently deviating from the trend and thus eliminating asset-price booms and busts.

Table 5. Optimal Feedback Coefficients on a Distributed Lag of the Indicators when All Variances Are Set to 0.0001

Indicator	Current Period	One-Period Lag	Two-Period Lag
k_t	1.197E-02	3.038E-03	2.226E-04
n_t	1.110E-02	2.818E-03	2.065E-04
ε_t	−1.708E-01	−4.248E-02	−2.744E-03
d_t	2.041E-01	4.884E-02	1.722E-03
k_t^*	1.305E-02	4.067E-03	9.743E-04
z_t	3.336E-02	6.360E-03	−1.022E-03
π_t	1.417E-03	2.201E-04	−8.246E-05
r_t^k	1.433E-03	2.700E-04	−4.645E-05
y_t	−1.779E-03	−2.763E-04	1.035E-04
mc_t	1.622E-02	2.520E-03	−9.442E-04
q_t	1.534E-03	2.383E-04	−8.930E-05
inv_t	−1.525E-02	−2.369E-03	8.874E-04
h_t	8.025E-03	1.246E-03	−4.670E-04
k_{t+1}	−2.121E-02	−3.294E-03	1.234E-03
n_{t+1}	−1.967E-02	−3.056E-03	1.145E-03
y_t^*	−7.993E-03	−9.027E-04	7.860E-04
h_t^*	−1.839E-03	−2.077E-04	1.808E-04
c_t^*	−4.683E-03	−5.289E-04	4.605E-04
k_{t+1}^*	−2.067E-02	−2.335E-03	2.033E-03
inv_t^*	−3.305E-02	−3.733E-03	3.250E-03
q_t^*	−3.187E-03	−3.600E-04	3.134E-04
r_t^*	4.683E-03	5.289E-04	−4.605E-04

5.3 Partial Information in the Credit Market

Among the reliable indicators, one may argue that some indicators may contain more noise than others. For instance, it may be more difficult for the central bank to observe the true values of the variables that reflect credit-market frictions, including net worth and the real return on capital. Thus, consider increasing the variance of these friction-related variables to 0.001. The variance of other reliable indicators, including capital stock, inflation, consumption, output, asset prices, investment, and labor supply, remains at 0.0001. The variance of productivity growth and the frictionless variables

Table 6. Optimal Feedback Coefficients on a Distributed Lag of the Indicators when the Variance of the Credit-Market-Friction-Related Indicators Is 0.001

Indicator	Current Period	One-Period Lag	Two-Period Lag
k_t	6.978E-03	3.641E-03	1.899E-03
n_t	6.473E-04	3.378E-04	1.761E-04
ε_t	−6.122E-02	−3.402E-02	−1.878E-02
d_t	6.126E-02	3.403E-02	1.878E-02
k_t^*	5.825E-04	9.600E-04	8.283E-04
z_t	4.102E-05	1.024E-05	4.740E-07
π_t	2.255E-03	4.373E-04	−9.439E-05
r_t^k	1.796E-04	4.402E-05	1.291E-06
y_t	−2.831E-03	−5.491E-04	1.185E-04
mc_t	2.582E-02	5.007E-03	−1.081E-03
q_t	2.442E-03	4.736E-04	−1.022E-04
inv_t	−2.427E-02	−4.706E-03	1.016E-03
h_t	1.277E-02	2.477E-03	−5.346E-04
k_{t+1}	−3.375E-02	−6.545E-03	1.413E-03
n_{t+1}	−3.131E-03	−6.072E-04	1.311E-04
y_t^*	2.132E-04	3.739E-04	3.259E-04
h_t^*	4.904E-05	8.602E-05	7.497E-05
c_t^*	1.249E-04	2.191E-04	1.910E-04
k_{t+1}^*	5.514E-04	9.671E-04	8.430E-04
inv_t^*	8.816E-04	1.546E-03	1.348E-03
q_t^*	8.502E-05	1.491E-04	1.300E-04
r_t^*	−1.249E-04	−2.191E-04	−1.910E-04

is still fixed at 0.1. This calibration is meant to capture a scenario in which the friction-related indicators are less accurately measured than other reliable indicators, but more accurately measured than the noisy indicators.

Table 6 provides the optimal feedback coefficients under this scenario. It is evident that the optimal feedback coefficient on asset prices becomes larger than those under the scenario in which credit-market frictions are perfectly observable. This implies that the role of asset prices, in the rate-setting process, should become even greater when there is uncertainty regarding the true state of the credit market.

This result also provides an implication on optimal policy responses prior to and during the subprime mortgage crisis in the United States, which began with housing bubbles during 2001–05, followed by the collapse of house prices and a sharp rise in home foreclosure since the summer of 2005. In this case, net worth, n_t in the model, can be interpreted as creditworthiness of U.S. households. Note also that s_t, the external finance premium, can be inferred from r_t^k, the real rate of return on capital; therefore, r_t^k can be interpreted as the U.S. households' risk premium. The result here thus suggests that if the central bank cannot verify the true state of creditworthiness and risk premiums of the U.S. households, movements in house prices will become an important indicator in predicting where the economy is heading. Under this condition, it would be optimal for the central bank to respond to movements in house prices particularly when the house prices *started* to rise in 2001 or *started* to fall in 2005.

5.4 Fundamental Values and Misalignments

Finally, notice that in every scenario under which optimal feedback coefficients are computed, asset prices are given larger weights than other price variables, such as inflation, but lower weights than most real-sector indicators, including labor supply. Even the one-period lag of labor supply is given a roughly equal weight to the asset prices in the current period. This result may provide a rationale for the belief held by financial markets that the FOMC and the Federal Reserve staff may pay some serious attention to labor-market indicators, such as non-farm payroll, and for the fact that the markets too are highly sensitive to any surprises in the monthly release of non-farm payroll figures.[16]

[16] A recent example is following the release of non-farm payroll on November 3, 2006 in which the actual release fell short of the market expectation for 13,000 jobs, the S&P 500 index jumped immediately by more than five points. See also Ramchander, Simpson, and Chaudhry (2005). Non-farm payroll is considered to be the most important economic indicator in financial markets because its release is very timely; it is released seven days following the end of the month being reviewed. Furthermore, non-farm payroll reflects household income and thus consumers' spending power, which accounts for two-thirds of the economy's total output. This is why financial markets consider non-farm payroll to be most informative in helping forecast future economic activity.

The question is, are there any scenarios in which it may be rational for the central bank to attach more weights to asset prices in the rate-setting process? One possibility is if asset prices are in fact more accurately measured. To examine this scenario, I run the optimal filtering problem by lowering the variance of asset prices to 0.000001, or $\frac{1}{100}$ of that of labor supply. The variances of all other reliable indicators and the noisy indicators remain at 0.0001 and 0.1, respectively.

Thus, this scenario corresponds to a situation when asset prices contain less noise than labor-market indicators. Arguably, it will be sensible to motivate this scenario if certain conditions are met. After all, it is extremely difficult, if not impossible, for the central bank to accurately observe the aggregate labor-market activities. As such, the central bank needs to rely on a number of labor-market indicators, all of which are derived from surveys. Thus, by default, labor-market indicators always contain at least some measurement errors, which in this case are captured by the variance of 0.0001 attached to them. Asset prices, however, can be readily observed from the markets. If what the central bank really needs to observe is the fundamental values, asset-price data retrieved from the markets can be fairly accurate, especially in the times when there is no bubble, or when market prices truly reflect the fundamentals.

As is evident from table 7, when this condition is met and therefore asset prices contain smaller noise than other indicators, the weights on asset prices in the reaction function rise significantly. In particular, the optimal feedback coefficient on asset prices in the current period is 0.20, the largest among all indicators in any horizons.

This result suggests that the usefulness of asset prices in the rate-setting process depends on the degree to which the central bank understands the nature of asset-price misalignments, or bubbles. Movements in the market values of assets should be given a prominent role in the rate-setting process when the central bank can distinguish the fundamental values from the misalignments. Under the scenario that there is uncertainty regarding whether movements in the market values of assets are driven by misalignments, it would be optimal for the central bank to also rely on other economic indicators.

Table 7. Optimal Feedback Coefficients on a Distributed Lag of the Indicators when Asset Prices Are More Accurately Measured Than Other Reliable Indicators

Indicator	Current Period	One-Period Lag	Two-Period Lag
k_t	6.068E-03	7.075E-03	4.317E-03
n_t	5.629E-04	6.563E-04	4.005E-04
ε_t	−6.122E-02	−6.936E-02	−4.209E-02
d_t	6.126E-02	6.936E-02	4.209E-02
k_t^*	5.814E-04	1.023E-04	4.628E-07
z_t	3.397E-05	6.526E-06	−2.321E-06
π_t	1.848E-03	−3.636E-05	−4.398E-04
r_t^k	1.486E-04	2.600E-05	−1.219E-05
y_t	−2.321E-03	4.565E-05	5.522E-04
mc_t	2.116E-02	−4.163E-04	−5.036E-03
q_t	2.002E-01	−3.937E-03	−4.763E-02
inv_t	−1.989E-02	3.913E-04	4.733E-03
h_t	1.047E-02	−2.059E-04	−2.491E-03
k_{t+1}	−2.766E-02	5.442E-04	6.582E-03
n_{t+1}	−2.566E-03	5.048E-05	6.106E-04
y_t^*	2.156E-04	3.769E-05	1.096E-06
h_t^*	4.959E-05	8.671E-06	2.521E-07
c_t^*	1.263E-04	2.209E-05	6.421E-07
k_{t+1}^*	5.575E-04	9.749E-05	2.834E-06
inv_t^*	8.913E-04	1.559E-04	4.532E-06
q_t^*	8.596E-05	1.503E-05	4.370E-07
r_t^*	−1.263E-04	−2.209E-05	−6.421E-07

6. Robustness

6.1 Variance of Noise to Indicators

In the analysis in the previous section, I set the variance of noise to the reliable indicators to 0.0001. The main results here, however, do not depend on the assumptions on the variance of noise. For example, consider varying the variance of noise to the reliable indicators to 0.001 and 0.00001. Table 8 reports the optimal feedback coefficients on the current-period asset prices and labor supply in these two cases. It is evident that with different variance of noise,

Table 8. Robustness Test on the Variance of Noise to Reliable Indicators

Scenario	Noisy Productivity Growth	Noisy Credit Friction	Asset Prices More Accurate
Var = 0.001			
h_t	5.218E-03	6.938E-03	5.686E-03
q_t	9.977E-04	1.327E-03	1.087E-01
Var = 0.00001			
h_t	1.818E-02	2.418E-02	1.981E-02
q_t	3.476E-03	4.623E-03	3.789E-01

the main results in this paper remain valid. That is, when it is more difficult for the central bank to verify the true state of the economy, the optimal feedback coefficients on asset prices become larger. Furthermore, across different scenarios in which labor supply and asset prices are equally accurate, it is optimal for the central bank to pay more attention to labor supply. Asset prices become more important only when labor supply is more noisy.

The same is true for the relative accuracy between the reliable and the noisy indicators. In the base-case analysis, the variance of noise to the reliable indicators is set to $\frac{1}{1000}$ of that to the noisy indicators. Table 9 reports the results from the robustness test in which the ratio is varied to $\frac{1}{100}$ and $\frac{1}{10000}$. With different degrees of

Table 9. Robustness Test on the Relative Accuracy between Reliable and Noisy Indicators

Scenario	Noisy Productivity Growth	Noisy Credit Friction	Asset Prices More Accurate
Relative Accuracy $\frac{1}{100}$			
h_t	5.218E-03	6.956E-03	5.699E-03
q_t	9.977E-04	1.330E-03	1.090E-01
Relative Accuracy $\frac{1}{10000}$			
h_t	1.785E-02	2.360E-02	1.942E-02
q_t	3.414E-03	4.512E-03	3.714E-01

Table 10. Robustness Test on Stabilization Weights

Scenario	Noisy Productivity Growth	Noisy Credit Friction	Asset Prices More Accurate
Varying λ to 0			
h_t	2.363E-04	3.143E-04	2.576E-04
q_t	4.519E-05	6.009E-05	4.925E-03
Varying λ to 2			
h_t	9.628E-03	1.280E-02	1.049E-02
q_t	1.841E-03	2.448E-03	2.007E-01
Varying ν to 0			
h_t	1.185E-02	1.576E-02	1.291E-02
q_t	2.266E-03	3.013E-03	2.470E-01
Varying ν to 0.5			
h_t	8.160E-03	1.085E-02	8.893E-03
q_t	1.560E-03	2.075E-03	1.701E-01

the relative accuracy between the reliable and the noisy indicators, we still derive the same conclusions as in section 5.

6.2 Stabilization Weights

In the base-case analysis, I follow Rudebusch and Svensson (1999) by setting the stabilization weights on the output gaps and interest rate smoothing to 1 and 0.2. Nevertheless, this assumption does not affect the main findings in this paper. Table 10 reports the results from the robustness test on the stabilization weights. On rows 1 through 6, λ, the weight on the output gap, is varied to 0 and 2 while ν is fixed at 0.2. On rows 7 through 12, ν is varied to 0 and 0.5 while λ is kept constant at unity. It is evident from the table that the main findings in this paper remain valid that the optimal feedback coefficient on asset prices becomes strictly different from zero when there is uncertainty regarding the state of the economy. The more difficult it is for the central bank to observe the state of the economy, the larger the optimal feedback coefficient on asset prices is. Finally, labor supply receives larger weights than asset prices when both are equally accurate; the optimal feedback coefficient on asset prices becomes larger only when labor supply contains more noise.

7. Conclusions

This paper examines the role of asset prices in the commitment equilibrium. It can be shown that asset prices are fully determined by the state of the economy. Hence, in the full-information case whereby the central bank can observe and respond to the state of the economy directly, there will be no further gain from setting the interest rate instrument to respond to asset prices.

In reality, however, it is unlikely that the central bank can perfectly observe the state of the economy. The paper finds that under the partial-information case, asset prices should enter the bank's rate-setting process with a weight strictly different from zero. There is a gain from responding to asset-price movements, because asset prices can provide signals on the developments in the state of the economy. The gain from responding to asset-price movements nonetheless depends on the degree to which the central bank understands the nature of asset-price misalignments. When there is uncertainty regarding whether movements in the market values of assets are driven by misalignments, it is advisable for the central bank to also rely on other economic indicators, including labor-market indicators.

In my future research, I plan to extend the analysis in this paper in several directions. First, it would be interesting to compare the implications regarding the role of asset prices under the commitment equilibrium with those when the central bank does not have access to a commitment device and thus follows discretionary policy.

Second, the present paper assumes that information is symmetric in the sense that private agents and the central bank have the same information set. In practice, this may not be true, and some may argue that private agents are more informed. I plan to examine whether the main findings in this paper are robust to such informational structure.

Finally, financial markets and financial instruments can be modeled explicitly and incorporated into the framework. This will allow us to examine a wider range of questions, including, for instance, the implications of value-at-risk and low-probability, extreme events on the role of asset prices.

Appendix 1. Presenting the GS Model into the State-Space Format

The GS model (1), (2), (3), (4), (5), (6), (7), (9), (10), (11), (12), (13), (14), and (15)–(22) can be presented into the canonical system (23), by defining the following sets of predetermined and non-predetermined variables:

$$X_t = \{k_t, s_{t-1}, n_t, \pi_{t-1}, \varepsilon_t, d_t, k_t^*, i_{t-1}, \mathrm{mc}_{t-1}\} \tag{35}$$

$$x_t = \left\{ \begin{matrix} c_t, z_t, \pi_t, r_t^k, y_t, \mathrm{mc}_t, q_t, \mathrm{inv}_t, s_t, h_t, k_{t+1}, n_{t+1}, \widehat{y}_t, y_t^*, \\ h_t^*, c_t^*, k_{t+1}^*, \mathrm{inv}_t^*, q_t^*, r_t^* \end{matrix} \right\}. \tag{36}$$

The elements of the corresponding matrices A, B, and C are available upon request.

Note that a key to make the analysis of optimal policy in this paper work is to define k_{t+1} and n_{t+1} as non-predetermined variables. This classification, however, is not out of the ordinary. Remember that under the GS model, k_{t+1} and n_{t+1} are in fact determined in period t. When one solves a rational-expectations model on dynare or gensys, a convention in these programs is that variables dated t are always known at t.[17] Thus, to assemble the model into these programs, one needs to write k_{t+1} and n_{t+1} as k_t and n_t, or treat k_{t+1} and n_{t+1} in the same way as all other variables dated t.

Appendix 2. Solving Optimal Policy under Commitment

Notice that problem (26) is not recursive, because non-predetermined variables, x_t, depend on expected future non-predetermined variables Hx_{t+1}. Thus, the practical dynamic-programming method cannot be used directly.

Nonetheless, as pointed out in Svensson (2006), this problem can be solved using the recursive saddlepoint method of Marcet

[17] See Collard and Juillard (2003) for an introduction to dynare and Sims (2002) for the algorithm used in gensys.

and Marimon (1998) by introducing a fictitious vector of Lagrange multipliers, Ξ_{-1}, equal to zero,

$$\Xi_{-1} = 0. \tag{37}$$

Then, the discounted sum of the upper term in the Lagrangian can be written

$$\begin{aligned} &\mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t [L_t + \Xi_t^{'}(Hx_{t+1} - A_{21}X_t - A_{22}x_t - B_2 i_t)] \\ &= \sum_{t=0}^{\infty} (1-\delta)\delta^t [L_t + \Xi_t^{'}(-A_{21}X_t - A_{22}x_t - B_2 i_t) + \frac{1}{\delta}\Xi_{t-1}^{'} H x_t]. \end{aligned}$$

It follows that the loss function (25) can be rewritten in terms of the dual-period loss:

$$\widetilde{L}_t \equiv L_t + \gamma_t^{'}(-A_{21}X_t - A_{22}x_t - B_2 x_t) + \frac{1}{\delta}\Xi_{t-1}^{'} H x_t, \tag{38}$$

where Ξ_{t-1} is a new predetermined variable in period t and γ_t is introduced as a new control. Ξ_{t-1} and γ_t are related by the dynamic equation,

$$\Xi_t = \gamma_t. \tag{39}$$

The optimal policy under commitment problem can then be reformulated as the recursive dual saddlepoint problem:

$$\max_{\{\gamma_t\}_{t\geq 0}} \min_{\{x_t, i_t\}_{t\geq 0}} \mathrm{E}_0 \sum_{t=0}^{\infty} (1-\delta)\delta^t \widetilde{L}_t$$

subject to (39) and

$$X_{t+1} = A_{11}X_t + A_{12}x_t + B_1 i_t + C\varepsilon_{t+1}. \tag{40}$$

Notice that the recursive dual saddlepoint problem is recursive where $\{x_t, i_t, \gamma_t\}$ are controls and $\{X_t, \Xi_{t-1}\}$ are predetermined. Here, we can use the standard solution for the linear quadratic regulator (LQR) problem.

Appendix 3. An Algorithm for Solving the Optimal Filtering Problem

Given that certainty equivalence holds and a separation principle applies, the optimal policy under commitment amid partial information satisfies

$$i_t = \widetilde{F} X_{t|t} + \Phi \Xi_{t-1} \tag{41}$$

$$x_{t|t} = G X_{t|t} + \Gamma \Xi_{t-1} \tag{42}$$

$$\Xi_t = S X_{t|t} + \Sigma \Xi_{t-1}, \tag{43}$$

where $\widetilde{F}$ and Φ, G and Γ, and S and Σ are appropriate matrices in F_i, F_x, and M, respectively, which are derived in section 3. $X_{t|t}$ denotes the central bank's estimate of the predetermined variables, given the information available in period t.

It should be noted that in this case, Ξ_{t-1} is the vector of the central bank's estimate of its promises from the past. Ξ_{t-1} is an estimate because it depends on the estimates of past predetermined variables,

$$\Xi_{t-1} = \sum_{\tau=0}^{\infty} \Sigma^{\tau} S X_{t-1-\tau|t-1-\tau}, \tag{44}$$

where (44) is derived from solving (43) backward.

Given that, the lower block of (23) implies

$$A_{21}(X_t - X_{t|t}) + A_{22}(x_t - x_{t|t}) = 0.$$

Substituting in (42) for $x_{t|t}$ leads to

$$x_t = G^1 X_t + G^2 X_{t|t} + \Gamma \Xi_{t-1}, \tag{45}$$

where

$$G^1 = -(A_{22})^{-1} A_{21}$$

$$G^2 = G - G^1.$$

Substituting (41) and (45) into the first row of (23) yields

$$X_{t+1} = T X_t + J X_{t|t} + \Psi \Xi_{t-1} + C \varepsilon_{t+1}, \tag{46}$$

where

$$T = A_{11} + A_{12}G^1$$
$$J = B_1\widetilde{F} + A_{12}G^2$$
$$\Psi = A_{12}\Gamma + B_1\Phi.$$

Equations (43) and (45)–(46) then describe the evolution of the predetermined and non-predetermined variables, X_t and x_t, once we determine the evolution of the estimates $X_{t|t}$ of the predetermined variables.

Note that (46) also implies

$$X_{t+1|t} = (T + J)X_{t|t} + \Psi\Xi_{t-1}. \tag{47}$$

Substituting (45) into (32), we obtain a measurement equation for an optimal filtering problem,

$$Z_t = LX_t + MX_{t|t} + \Lambda\Xi_{t-1} + v_t,$$

where

$$L = \widetilde{D}_1 + \widetilde{D}_2G^1$$
$$M = \widetilde{D}_2G^2$$
$$\Lambda = \widetilde{D}_2\Gamma$$

and $\widetilde{D}_1$ and $\widetilde{D}_2$ are appropriate matrices in $\widetilde{D}$.

The optimal linear prediction of X_t is then given by a Kalman filter,

$$X_{t|t} = X_{t|t-1} + K(Z_t - LX_{t|t-1} - MX_{t|t} - \Lambda\Xi_{t-1}). \tag{48}$$

Svensson and Woodford (2003) show that the Kalman gain matrix K is given by

$$K = PL'(LPL' + \Sigma_{vv})^{-1}, \tag{49}$$

where the matrix $P \equiv \text{Cov}\ [X_t - X_{t|t-1}]$ is the covariance matrix for the prediction errors $X_t - X_{t|t-1}$ and fulfills

$$P = T[P - PL'(LPL' + \Sigma_{vv})^{-1}LP]T' + CC'. \tag{50}$$

To find optimal weights on the indicators Z_t in the estimation of the state of the economy, use the prediction equation (48) to solve for $X_{t|t}$ to get

$$X_{t|t} = (I + KM)^{-1}[(I - KL)X_{t|t-1} - K\Lambda\Xi_{t-1} + KZ_t].$$

We can then use (43) and (47) to express the dynamic equation for $X_{t|t}$ in terms of $X_{t-1|t-1}$ and Ξ_{t-2},

$$\begin{aligned} X_{t|t} = (I + KM)^{-1}\{&[(I - KL)(T + J) - K\Lambda S]X_{t-1|t-1} \\ &+ [(I - KL)\Psi - K\Lambda\Sigma]\Xi_{t-2} + KZ_t\}. \end{aligned}$$

Solving the system consisting of this equation and (43) backwards, $X_{t|t}$ can be expressed as the weighted sum of current and past indicators,

$$X_{t|t} = \sum_{\tau=0}^{\infty} Q_\tau K Z_{t-\tau},$$

where Q_τ is the upper-left submatrix of the matrix

$$\begin{bmatrix} (I + KM)^{-1}[(I - KL)(T + J) - K\Lambda S] & (I + KM)^{-1}[(I - KL)\Psi - K\Lambda\Sigma] \\ S & \Sigma \end{bmatrix}^{\tau}.$$

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Using Intraday Data to Gauge Financial Market Responses to Federal Reserve and ECB Monetary Policy Decisions*

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This paper examines bond and stock market volatility reactions in the euro area and the United States following their respective economies' monetary policy decisions, over a uniform sample period (April 1999–May 2006). For this purpose, intraday data on the U.S. and euro-area bond and stock markets are used. A strong upsurge in intraday volatility at the time of the release of the monetary policy decisions by the two central banks is found, which is more pronounced for the U.S. financial markets following Federal Reserve monetary policy decisions. Part of the increase in intraday volatility in the two economies surrounding monetary policy decisions can be explained by both news of the level of monetary policy and revisions in the expected future monetary policy path. The observed strong discrepancy between asset-price reactions in the United States and in the euro area following monetary policy decisions still remains a puzzle, although some tentative explanations are provided in the paper.

JEL Codes: E52, E58, G14.

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1. Introduction

How do financial markets react to the release of monetary policy decisions? The answer to this question is of fundamental interest to monetary policymakers, as it provides them with information as to first, how well decisions are anticipated by market participants, and second, how these agents adjust their views about future monetary policy, output growth, and inflation in response to a given decision. Such information enables a central bank to judge the immediate "success" of any decision taken, i.e., whether market participants reacted in accordance with the policymakers' intentions.

The purpose of this paper is to assess bond and stock market reactions in the euro area and the United States following monetary policy decisions by the European Central Bank (ECB) and the Federal Reserve over a uniform sample period (April 1999–May 2006). Intraday data are used, and the asset-price reaction is measured in terms of derived realized volatility measures over five-minute intervals. Two different angles are viewed. First, asset-price volatility on monetary policy announcement days is compared with the volatility observed on non-announcement days. Second, the volatility pattern when the central bank changes policy rates as opposed to when the monetary policy rates are left unchanged is examined. Conditional on these two events, the extent to which monetary policy target and path surprises can explain the observed volatility is analyzed.

The paper contributes to the existing literature in two main aspects. First, a direct comparison of the U.S. and euro-area bond and stock market intraday volatility patterns following monetary policy decisions is novel. Second, this paper is the first to examine the influence that monetary policy target and path surprises exert on intraday financial market volatility patterns, conditional on whether monetary policy rates have been altered or not.

The paper reaches three main findings. First, intraday U.S. and euro-area stock and bond market volatility strongly increases at the time of the release of monetary policy decisions and is particularly pronounced for the U.S. financial markets. Second, monetary policy target and path surprises by the ECB both significantly move the euro-area financial markets, whereas path surprises by the Federal Reserve have, on average, a larger influence on U.S. bond and stock market volatility compared with the target surprises. Third, the yield response sensitivity for the German bond markets following an ECB monetary policy target surprise is stronger on the occasions when the monetary policy rates have been altered compared with periods when the ECB decided to leave it unchanged.

Although some tentative explanations are given in the paper, the observed discrepancy between asset-price reactions in the United States and in the euro area following monetary policy decisions still remains a puzzle.

The remainder of this paper is organized as follows. Section 2 presents some background and related literature, while section 3 discusses the data used. The bond and stock market volatility reactions in the euro area and the United States following their respective economies' monetary policy decisions are elaborated upon in section 4. Section 5 concludes.

2. Background and Related Literature

Volatility of prices of financial assets such as stocks and bonds surrounding monetary policy decisions can be used to gauge the extent to which they contain "new news" for market participants that would lead them to revise their expectations about the future monetary policy path and/or the macroeconomic outlook. If a monetary policy decision causes market participants to revise their expectations, this should then be reflected in higher volatility of financial market prices compared with a period free of such an event.

Several differences can be noted in both the frequency and magnitude of interest rate settings between the two central banks (see table 1). First, the ECB conducts monetary policy decisions meetings more frequently compared with the Federal Reserve. Second, the Federal Reserve has, on average, changed the interest rate more often and by larger magnitudes than the ECB over recent years.

Both the degree of predictability of monetary policy decisions and the influence the decisions exert on financial asset prices have been discussed in the literature. As regards the former, many papers have shown that U.S. monetary policy decisions in general have been well anticipated among market participants (see, for example, Bernanke and Kuttner 2004 and Fleming and Piazzesi 2005). The same holds true for the euro area, where financial markets have also been able to foresee the ECB's monetary policy decisions (see,

Table 1. Federal Reserve and ECB Monetary Policy Decisions (April 1999–May 2006)

	ECB	Federal Reserve
Total Number of Events	118	54
Number of Events in Which the Monetary Policy Stance Was Changed	16	32
Number of Increases, 25 bp	7	21
Number of Increases, 50 bp	2	1
Number of Reductions, 25 bp	3	4
Number of Reductions, 50 bp	4	6

Notes: In this study, for comparison, the data start in April 1999, as the ECB then began to release its monetary policy decisions at the regular time of 13:45 (CET). All statistics exclude the September 17, 2001 observation. Unscheduled monetary policy meetings by the Federal Reserve are also excluded.

for instance, Wilhelmsen and Zaghini 2005 and European Central Bank 2006). In addition, monetary policy communication plays a key role in enhancing short-term predictability by allowing the public to understand monetary policy decisions, a fact which has been documented in a number of studies by Ehrmann and Fratscher (2005a, 2005b, and 2007).

A number of papers have also examined the impact monetary policy decisions exert on the level of financial asset prices. Applied to U.S. data, Gürkaynak, Sack, and Swanson (2005) and Wongswan (2006) find that the U.S. stock and bond markets react significantly to news about the near-term level of monetary policy and to changes in expectations of the path of monetary policy. Similarly, for the euro area, Brand, Buncic, and Turunen (2006) suggest that revised ECB monetary policy expectations have a significant and sizable impact on the level of medium- to long-term interest rates in the euro area. In a closely related paper, Rosa (2008) adopts yet another approach and compares, among other things, the ability of the ECB and the Federal Reserve to influence domestic interest rates by means of various communication channels. By contrast with this paper, Rosa evaluates the way in which central bank communication affects the direction of asset-price movements. The results show that long-term bond yields in the United States are more sensitive to the Federal

Table 2. Data Used To Measure Financial Market Reactions

Asset	Exchange
German Bond Futures	EUREX
U.S. Bond Futures	Chicago Board of Trade
EURO STOXX 50 Futures	EUREX
S&P 500 Index	Chicago Mercantile Exchange

Reserve's statements than European bond yields are to statements by the ECB.

Fewer studies have been conducted on volatility reactions surrounding monetary policy communications. Applied to the United States, Andersen et al. (2005) find a significant rise in U.S. long-term bond yield volatility surrounding monetary policy decisions by the Federal Reserve. Similarly, Ehrmann and Fratzscher (2003) show that the volatility on euro-area money market rates tends to be higher following Governing Council statements by the ECB. This paper fills a gap in the existing literature by conducting a direct comparison between the U.S. and euro-area bond and stock market intraday volatility pattern following monetary policy decisions.

3. Description of Data Used

The data used to measure financial market reactions consist of intraday data on euro-area and U.S. bond and stock prices (see table 2).

The data have been provided by TickData, Inc. The dates and times of when the Federal Reserve's monetary policy decisions have become available to the public are taken from the paper by Fleming and Piazzesi (2005).[1] The actual and expected outcome of the Federal Reserve's interest rate decisions are taken from the Bloomberg survey. The dates and times for the ECB's monetary policy decisions have been collected internally. With regard to market expectations for ECB monetary policy decisions, the expected outcome from the Reuters survey is used.

[1] The exceptions are the 2005 and 2006 decisions, which are taken from Bloomberg.

Table 3. Descriptive Statistics, Five-Minute Returns

	German Bond Futures	U.S. Bond Futures	EURO STOXX 50 Futures	S&P 500 Index
Mean	0.0001	0.0001	−0.0001	−0.0003
Standard Deviation	0.0258	0.0398	0.1252	0.1048
Skewness	−0.24	−0.30	−0.57	0.16
Kurtosis	17.73	55.07	37.82	12.43

Notes: April 1999–May 2006. The overnight returns are omitted when computing the descriptive statistics.

This paper derives a volatility measure V using regularly spaced five-minute intervals:

$$V_t = abs\left(100 * \log\left(\frac{P_t}{P_{t-1}}\right)\right), \tag{1}$$

where P_t is the five-minute prices of the four assets.[2]

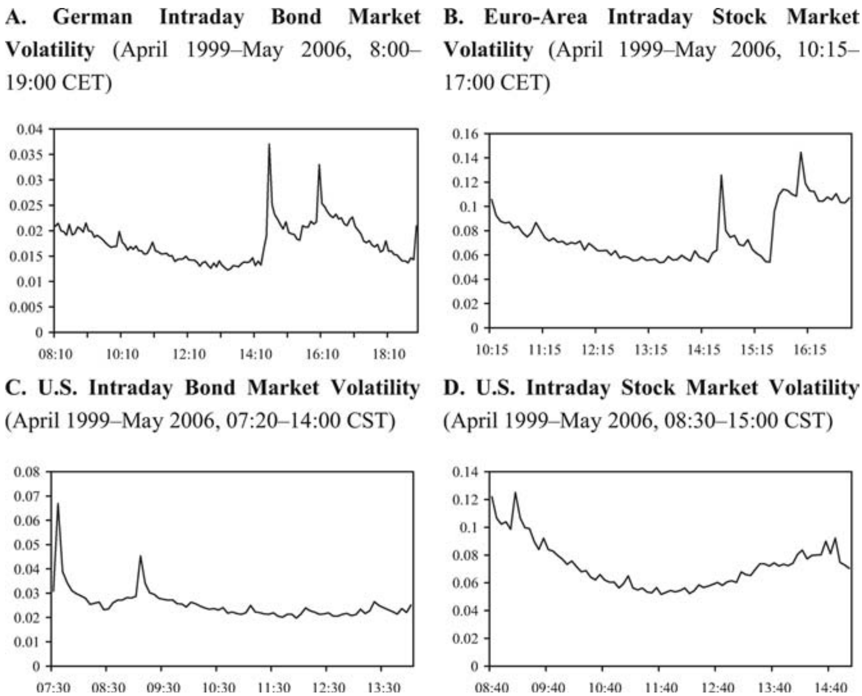
Table 3 summarizes the descriptive statistics for the four return series used in the paper. The sample mean of the asset returns are all small and, given the sample standard deviations, not statistically different from zero. The returns are obviously not normally distributed, given the large magnitudes of the skewness and kurtosis statistics.

Volatility is normally not constant throughout a trading day, but tends to be higher at opening and closing hours than during the middle of a trading day. This feature has to be taken into account when gauging whether policy decisions by central banks induce elevated price fluctuations. Figures 1A–1D show the average five-minute volatility during the trading days for the U.S. and euro-area bond and stock series.[3]

[2]As an alternative, the squared return could also be used as a measure of realized intraday volatility. This measure does not, however, change the interpretations.

[3]Over the sample under consideration, the trading hours of the STOXX futures and the German bond futures have not remained constant. The intraday volatility shown in figures 1A and 1B is therefore calculated using only hours which have been traded over the entire sample.

Figure 1. Intraday Volatility in the Euro-Area and U.S. Stock Markets



The German bond and euro-area STOXX future contracts display a number of interesting intraday features (figures 1A and 1B). First, volatility in general tends to be higher at the opening and closing hours of the trading day. At opening hours, prices normally have to adjust to new information, which may induce heightened price fluctuations. Higher volatility close to the end of the trading day is probably linked to some investors closing their trading books to avoid having open positions overnight. Second, the two spikes—occurring at 14:30 and 16:00 (Central European time, or CET)—correspond to the release of several important U.S. macro announcements, such as the non-farm payroll, producer price index, retail sales, consumer price index, ISM, and consumer confidence. In addition, at 14:30 on the first Thursday of each month, the ECB holds a press conference at which information about the considerations concerning the monetary policy decision is conveyed. Third, the level of intraday volatility is higher for the euro-area stock markets compared with the German bond future markets, which is something that is also observed for much lower frequencies such as daily data.

The U.S. bond and stock markets show a broadly similar pattern to their European counterparts (figures 1C and 1D). The spikes occurring at 07:30 and 09:00 (central standard time, or CST) mainly arise from releases of the above-reported U.S. macro announcements. Overall, bond and stock markets on both sides of the Atlantic seem to display generally similar levels of volatility.

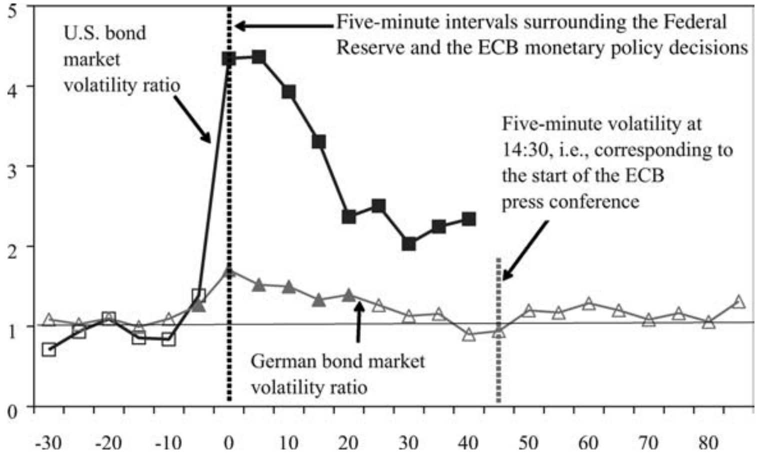
4. Asset-Price Reactions Following Monetary Policy Decisions by the ECB and the Federal Reserve

The following four subsections examine financial market intraday volatility patterns surrounding monetary policy decisions by the ECB and the Federal Reserve. Target and path surprises implicitly embedded in the monetary policy decisions are computed. These surprises are used as explanatory variables to the observed intraday volatility pattern. In section 4.1 the general volatility pattern is analyzed. Section 4.2 provides some tentative explanations for the observed discrepancy between asset-price reaction in the United States and in the euro area following monetary policy decisions. Section 4.3 regresses the general intraday volatility pattern on monetary target and path surprises. Section 4.4 evaluates if the volatility pattern in financial markets differs depending on if monetary policy rates have been altered or not.

4.1 General Intraday Volatility Pattern Surrounding Monetary Policy Decisions

Figures 2 and 3 display the ratio between five-minute bond and stock market volatility surrounding monetary policy decisions by the Federal Reserve and the ECB, respectively, and the average five-minute volatility on the same weekdays and the same times but on non-announcement days, thereby controlling for both intraday and "weekday" effects. A ratio above 1 can be interpreted as the monetary policy decisions inducing "higher than normal" volatility. As regards the timing, the Federal Reserve's interest rate decisions are

Figure 2. U.S. and German Bond Market Volatility Ratio Surrounding Monetary Policy Decisions by the Federal Reserve and the ECB (April 1999–May 2006)



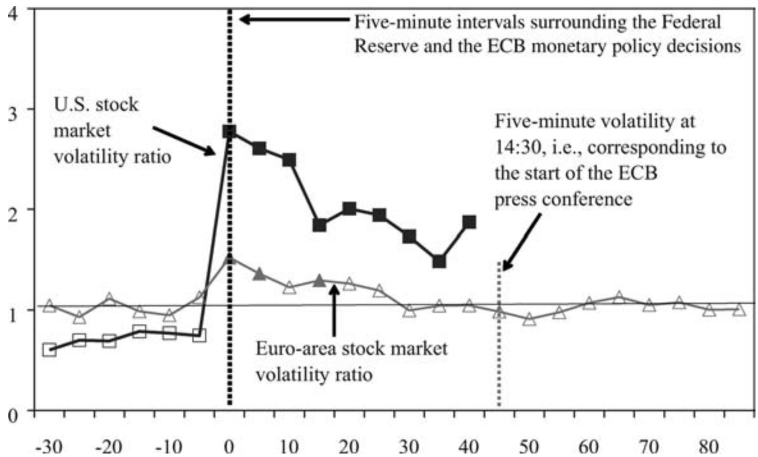
Notes: The volatility measures are calculated as the ratio between (i) five-minute intraday volatility on the U.S. and German long-term bond futures markets surrounding interest rate decisions by the Federal Reserve and the ECB, and (ii) "normal volatility," the latter computed as the average absolute returns on the same weekdays and same times but on non-announcement days. Using a one-sided t-test, the filled dots imply that the ratio is significantly higher than 1 and empty dots that the ratio cannot be deemed as exceeding 1.

usually released at 13:15, and the ECB's interest rate decisions at 13:45 (both local times).

It should be noted that the Federal Reserve's interest decisions are also accompanied by a statement in which the outlook for the future monetary policy stance is conveyed.[4] This implies that, particularly for the Federal Reserve, there are two potential sources of new information arising from the interest rate decisions—a target surprise and a path surprise. The target surprise can be defined

[4]The trading of the U.S. ten-year Treasury future note closes at 14:00 (CST), i.e., forty-five minutes after the Federal Reserve's interest rate decisions. To enable a consistent comparison between the U.S. bond and stock markets, the volatility window spans from thirty minutes before to forty minutes after the decisions for these two markets.

Figure 3. U.S. and Euro-Area Stock Market Volatility Ratio Surrounding Monetary Policy Decisions by the Federal Reserve and the ECB (April 1999–May 2006)



Notes: The volatility measures are calculated as the ratio between (i) five-minute intraday volatility on the U.S. (S&P 500) and euro-area (EURO STOXX) stock markets surrounding interest rate decisions by the Federal Reserve and the ECB, and (ii) "normal volatility," the latter computed as the average absolute returns on the same weekdays and same times but on non-announcement days. Using a one-sided t-test, the filled dots imply that the ratio is significantly higher than 1 and empty dots that the ratio cannot be deemed as exceeding 1.

as the degree to which market participants have been able to anticipate the actual monetary policy decisions. The path surprise instead measures to what degree market participants have revised the future expected monetary policy path following the actual decision and/or monetary policy statements.

In contrast to the Federal Reserve, the ECB's interest decisions and statements are released to the public at separate times. Announcements of the actual outcome of monetary policy decisions are released at 13:45 local time. However, details about the economic and monetary analyses underlying each interest rate decision are instead conveyed in the introductory statement read by the ECB President forty-five minutes later. As seen in the figures, the volatility pattern for the euro-area bond and stock markets is therefore extended to include any financial market movements that take place surrounding the press conference as well.

Four interesting features can be inferred from the two figures. First, monetary policy decisions on both sides of the Atlantic tend to induce significantly "higher than normal" volatility on their respective economies' bond and stock markets. Second, this feature seems to be particularly pronounced for the U.S. bond and stock markets following interest rate decisions by the Federal Reserve. Third, some volatility persistence can be observed, in particular for the U.S. bond and stock markets, where "excess" volatility can be noted up to forty minutes after the decisions have taken place. Fourth, in the euro area, the introductory statement read by the ECB President induces somewhat "higher than normal" volatility on the euro-area bond market.

Potentially, any interpretations on the basis of figures 2 and 3 could be spurious if important macro announcements were systematically released on the same days and at the same times as the monetary policy decisions of the Federal Reserve and the ECB. To examine this in detail, forty-three U.S. and euro-area macro announcements were collected and tested to establish whether they were made within a sixty-minute window of the monetary policy announcements by the two central banks.[5] The results of this examination suggested that none of the announcements under consideration occurred at the same time as the Federal Reserve decisions. The monetary policy decisions of the ECB coincided with the release of macro statistics on only two occasions, and both concerned the German CPI statistics released on March 23, 2001 and April 26, 2001. These two instances of concurrence should not, however, distort the interpretation, as previous announcement papers have found that the German CPI does not move the euro-area financial markets in any significant way—see Ehrmann and Fratzscher (2003) and Andersson, Hansen, and Sebestyén (2006).

The small number of macro releases occurring at the time of the monetary policy decisions suggests that the observed upsurge in volatility is prompted by the actual decisions and does not reflect market reactions to macro news. In stark contrast, the ECB press conference is usually held at times of important U.S. macro

[5]See Andersson, Hansen, and Sebestyén (2006), table 1, where the forty-three announcements are listed.

announcements—in particular, the weekly initial jobless claims—making the volatility ratio difficult to interpret.[6] An analysis of the ECB press conference is, however, outside the scope of this paper, which purely concentrates on market reaction to the actual decisions.

The average reaction to asset prices shown in figures 2 and 3 may not be static but, rather, changing over time. There are several reasons why price reaction can change over time. Andersson, Hansen, and Sebestyén (2006) suggest that policymakers can sometimes signal a preference for one or more macroeconomic indicators as input for their policy decisions. In addition, some macroeconomic releases may behave in an unusual manner at a certain point in the business cycle, which can in turn have an impact on monetary policy decisions. To check for potential time variation, yearly averages were computed.[7] The yearly averages are broadly similar across the years, suggesting that the pattern shown in figures 2 and 3 can be deemed a general feature.

4.2 Why Intraday Asset-Price Movements Are Stronger in the United States Than in the Euro Area: Some Tentative Explanations

The finding that there is a higher intraday asset-price reaction in the United States than in the euro area following their respective economies' monetary policy decisions is interesting but somewhat puzzling. The three best possible explanations for this discrepancy, in order of significance, are as follows. First, "more" information becomes available during the release of Federal Reserve interest rate decisions. This comes from the fact that U.S. interest rate decisions are released together with an accompanying statement that contains crucial information about the future monetary policy stance, as seen

[6]Over the sample April 1999–May 2006, the initial jobless claims announcement was released within a sixty-minute window surrounding the 14:30 press conference 106 times. Similarly, the release of the Philadelphia Federal Index occurred five times, durable goods two times, business inventories three times, retail sales four times, CPI two times, advanced GDP three times, GDP preliminary two times, and GDP final two times.

[7]See appendix A in the working paper version (ECB Working Paper No. 726). It shows the yearly volatility ratios for the five-minute periods immediately surrounding and thirty minutes ahead of the monetary policy decisions, respectively.

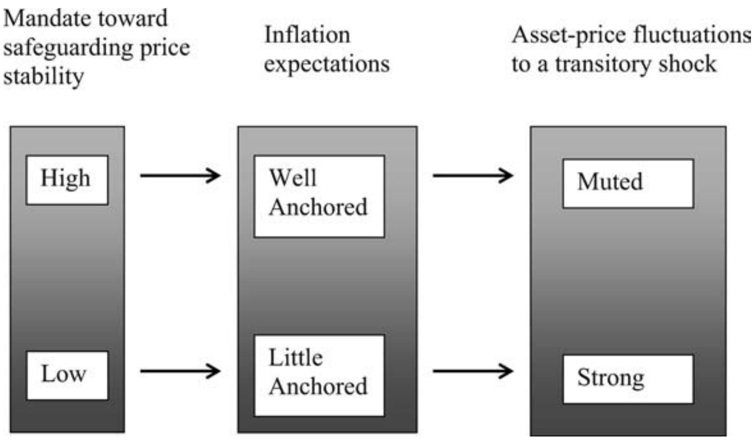
through the eyes of the Federal Reserve. In contrast, the ECB monetary policy decisions are not accompanied by any forward-looking statement.

As a consequence of the Federal Reserve communication strategy, even though the actual decisions by the Federal Reserve have been anticipated by the markets, heightened volatility could still arise given an unexpected change in the tone of the accompanying statement. An interesting example of this took place in January 2004 when the Federal Reserve, as expected, held the policy rate unchanged (at 1 percent) but at the same time significantly changed its wording in the statement following the decision. As the *Wall Street Journal* wrote in its market commentary column the day after the decision, "While investors had expected the Fed's decision to keep short-term interest rates on hold at 1%, the absence of the 'considerable period' phrasing, used since August 2003 to describe how long the bank would keep rates low, caught market participants off guard. . . . Prices plummeted in the immediate aftermath of the Fed's decision and the yield on the 10-year note shot up to 4.26%."

Second, part of the asymmetric asset-price responses in the two economies may be derived from the differences in mandates given to the central banks. Similarly, Orphanides and Williams (2005) introduce learning in a two-equation macroeconomic model where the central bank aims at minimizing a loss function that equals the variance of the output gap and deviations of actual inflation from a target rate. Instead of assuming that all agents know perfectly the structure of the economy and the central bank's policy, agents form expectations based on learning. The authors show that this setup is consistent with excess sensitivity of long-run inflation expectations and long-term bond yields to transitory aggregated shocks. The magnitude of the positive correlation between transitory shocks on the one hand and inflation expectations (and asset-price fluctuations) on the other is smaller if the central bank is vigilant in responding to inflationary threats and the public can be certain of its long-run inflation expectations.

Very simplified, the right-hand panel in figure 4 shows the results proposed by Orphanides and Williams (2005), namely that asset-price fluctuations to transitory shocks tend to be less pronounced for those economies with inflation expectations anchored more firmly. Furthermore, how well market participants' inflation expectations

Figure 4. Central Bank Mandate and Asset-Price Movements



are anchored partly originates from the inflation mandate given to the central bank. As shown by Gürkaynak, Levin, and Swanson (2007), inflation targeting helps to anchor private-sector perceptions of the future distribution of long-run inflation outcomes. The authors show that government bond yields in the United States and the United Kingdom (prior to Bank of England independence) respond significantly to economic news while little movements can be found in the United Kingdom after central bank independence and in Sweden. In the same vein, Rosa (2008) suggests that the asymmetric asset-price responses in the two economies can be linked to the fact that the U.S. long-term inflation objective is not well known to investors.

For the purpose of this paper, the first feature to note is the differences in mandates given to the Federal Reserve and the ECB. The Federal Reserve Act states that the Federal Reserve should seek "to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates" whereas the ECB has a price stability objective, laid down in the Maastricht Treaty. The price stability objective has been quantified by the ECB (in May 2003) to aim at inflation rates of below, but close to, 2 percent over the medium term. Thus, even though the objectives of the central banks in this study differ less than those of the central banks included in the study by Gürkaynak, Levin, and Swanson (2007), it would be safe to say that the ECB has a greater orientation toward price stability than the Federal Reserve.

Partly on account of the different inflation objectives, the question then arises if inflation expectations, in the eyes of investors, differ across the Atlantics. To this end, a recent study by Beechey, Johannsen, and Levin (2007) derives comparable survey-based measures of inflation expectations in the United States and in the euro area (using the ECB Survey of Professional Forecasters and the Federal Reserve Bank of Philadelphia Survey of Professional Forecasters).[8] The authors show that inflation expectation is higher and more volatile in the United States than in the euro area over the 2000–06 period. In addition, the Survey of Professional Forecasters data also allow for an assessment of the uncertainty surrounding the most likely outcome, as the survey respondents report their respective probabilities of inflation outcomes falling into prespecified intervals. Using these additional data, evidence is provided that the disagreements between forecasters are higher in the United States than in the euro area.[9]

All in all, bringing together the theoretical results by Orphanides and Williams (2005) and the fact that long-term inflation expectations seem to be less firmly anchored in the United States than in the euro area gives some economic justification to the asymmetric asset-price responses in the two economies.

Third, uncertainty regarding the timing of the Federal Reserve decisions may also explain part of the differences in asset-price fluctuations. Fleming and Piazzesi (2005) suggest that some uncertainty exists about the exact release of the U.S. monetary policy announcements, which in turn have an impact on intraday market pricing in the U.S. Treasury markets. In particular, liquidity tends to be

[8] See figures 1 and 2 in Beechey, Johannsen, and Levin (2007).

[9] It should, however, be pointed out that disagreement, measured by the standard deviation of the panelists' point estimates, can differ substantially from investors' true uncertainty about long-term inflation expectations; see Giordani and Söderlind (2003) and García and Manzanares (2007b). In addition, the presence of substantial heterogeneity in the central tendencies reported as point estimates may also distort the degree of disagreement (for U.S. evidence, see Engelberg, Manski, and Williams 2007 and for the euro area, see García and Manzanares 2007a).

low if an announcement is released minutes later than the expected 13:15. Everything else held equal, a buy or sell order during imperfect liquidity conditions should result in higher asset-price responses compared with periods of high financial market liquidity. In contrast, timing uncertainty for the ECB's monetary policy decisions should not exist given the exact 13:45 release.

4.3 Evaluating the Impact Monetary Policy Surprises Have on Intraday Financial Market Volatility

All in all, it is reasonable to assume that the arrival of new information could induce heightened volatility surrounding monetary policy releases. To assess this in more detail, this and the next subsection will focus on the strong upturn observed at the time "0" in figures 2 and 3, which corresponds to the realized asset-price volatility immediately surrounding the monetary policy decisions by the Federal Reserve and the ECB, respectively. The idea is to analyze to what extent the upswing in volatility can be explained by monetary policy surprises.

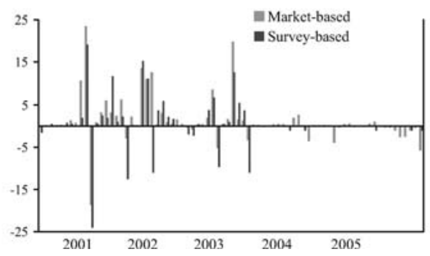
Monetary policy surprises are divided into two types: target surprises and path surprises. A target surprise is defined as the degree to which market participants have been able to anticipate the actual monetary policy decisions, whereas a path surprise measures the degree to which market participants have revised the future expected monetary policy path following the actual decision and/or monetary policy statements.

The target surprise can be derived from either available surveys or financial market prices. Both measures have their pros and cons. The main advantage of the former is that, in principle, they should contain the "true" mean expectations about upcoming future monetary policy decisions. On the other hand, financial market expectations benefit from the fact that they are available at a much higher frequency compared with survey-based measures. But, as shown by Piazzesi and Swanson (2004) and applied to U.S. data, expectations derived from the financial markets could contain risk premia and market noise, which may blur the interpretation.

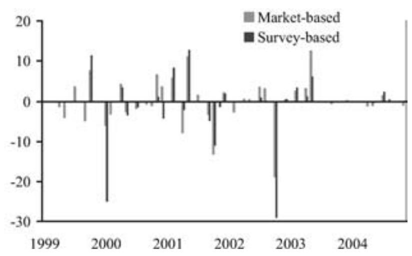
This paper uses a survey-based measure for the target surprise which represents the difference between the actual outcomes and the mean of analysts' expectations concerning the outcomes

Figure 5. Market- and Survey-Based Target Surprises

A. ECB (November 2000–April 2006)



B. Federal Reserve (February 1999–December 2004)



Notes: (A) The market-based measure comes from Brand, Buncic, and Turunen (2006) and represents the thirty-minute changes in the thirty-day maturity euro-area interest rates surrounding the ECB monetary policy decisions (interest rates are filtered using sixty-four instruments; deposit rates, EONIA and EURIBOR swap rates). The survey-based measure represents the difference between the actual outcome of the monetary policy decisions and analysts' mean expectations taken from the Reuters survey. (B) The market-based measure comes from Fleming and Piazzesi (2005) and represents the one-hour changes in federal fund futures contracts surrounding the Federal Reserve monetary policy decisions. The survey-based measure represents the difference between the actual outcome of the monetary policy decisions and analysts' mean expectations taken from the Bloomberg survey.

of the monetary policy decisions. This measure is chosen because the methodology used is identical for both the euro area and the United States. As a cross-check, figures 5A and 5B show the target surprise used in this paper compared with market-based measures employed in some earlier studies. Overall the two measures exhibit very similar patterns, which are also confirmed by the estimated correlation coefficients of 0.75 for the ECB target surprises and 0.8 for the Federal Reserve target surprises. Thus, the survey-based measure should therefore be a good indicator of the target surprise as perceived among investors.

The path-surprise component employed in this study is derived in line with Gürkaynak, Sack, and Swanson (2005):

$$\Delta f_{t-30,t} = \alpha + \beta^{*} TS_t + PS_t, \tag{2}$$

where $\Delta f_{t-30,t}$ represents the intraday changes in the expected three-month interest rate in six months' time surrounding the monetary policy decisions (Euribor and Eurodollar future contracts for the euro area and the United States, respectively). The *TS* represents the target-surprise component as described above. The innovation from the regression in equation (2) is defined as the path surprise (*PS*).[10] Given that the purpose of this exercise is to examine the effects on financial markets surrounding the actual monetary policy decisions, potential information about future ECB monetary policy conveyed in the introductory statement at the ECB press conference is not included in the derived ECB path surprises.

To evaluate how the changes in the volatility ratios surrounding the monetary policy decisions by the Federal Reserve and the ECB as shown in figures 2 and 3 can be explained by the target and/or path surprises, the following regression setup is used:

$$\Delta Volratio_{t-30,t} = \alpha + \beta_1{}^{*} Abs(TS) + \beta_2 Abs(PS) + \varepsilon_t. \qquad (3)$$

The $Abs(TS)$ and $Abs(PS)$ variables in equation (3) correspond to the absolute values of the target and the path surprises, respectively. The $\Delta Volratio_{t-30,t}$ represents the difference between the observed volatility ratio in the period immediately surrounding the monetary policy decisions and the volatility ratio thirty minutes ahead of the decisions. The appendix shows details of how the volatility ratio is calculated. The choice of the intraday impact relative to that of non-announcement days as a dependent variable is in line with the procedure by Ederington and Lee (1993). Table 4 outlines the results of the regression.

Three notable features can be inferred. First, a monetary policy target surprise induces significantly higher than normal volatility in the German bond markets. Second, the ECB path surprises have a highly significant impact on the euro-area stock markets. Third, in the United States the results suggest that path surprises, on average, have a larger influence on the U.S. bond and stock market volatility compared with target surprises.

[10] The derived path surprise may be distorted by the term premium investors usually demand to hold government bonds. However, it is reasonable that the term premia demanded on shorter-maturity bonds are relatively small in magnitude and remain broadly unchanged on an intraday basis. As a result, the bulk of the five-minute changes in near-term forward rates surrounding monetary policy decisions should accurately capture investors' revisions in future monetary policy path and, to a lesser extent, revisions in the term premia they demand.

Table 4. Regression Results

Dependent Variable $\Delta Volratio_{t-30,t}$	**Constant**	***Abs*(*TS*)**	***Abs*(*PS*)**	**R2**	**Corr (*Abs*(*TS*), *Abs*(*PS*))**
German Bond Markets	−0.34* (0.18)	0.22*** (0.09)	0.29 (0.24)	0.38	0.56
Euro-Area Stock Markets	−0.64*** (0.13)	0.06* (0.04)	0.90*** (0.12)	0.38	0.56
U.S. Bond Markets	1.25* (0.70)	−0.10 (0.09)	0.77*** (0.20)	0.40	0.10
U.S. Stock Markets	0.82 (0.68)	−0.05 (0.06)	0.43** (0.21)	0.20	0.10

Notes: The regression specifications are $\Delta Volratio_{t-30,t} = \alpha_{1,t} + \beta_1 * Abs(TS) + \beta_2 * Abs(PS) + \varepsilon_t$ for the four asset classes, respectively. $\Delta Volratio$ represents the changes in the volatility ratio (thirty minutes before and five minutes after the monetary policy decisions) between observed volatility on monetary policy events and volatility on non-announcement days. $Abs(TS)$ and $Abs(PS)$ correspond to the absolute values of the target and the path surprises, respectively. Newey-West heteroskedasticity-consistent standard errors are in parentheses. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

One potential problem with the equation (3) regression specification could be presence of multicollinearity between the explanatory variables. However, the classic symptoms of multicollinearity, such as (i) high R2 and few significant t-ratios and (ii) high pairwise correlations between the regressors, cannot be detected. This suggests that it should be possible to isolate the individual impact that the target and the path surprises have on financial market prices.

4.4 Impact of Monetary Policy Surprises on Intraday Financial Market Volatility, Conditional on Whether Policy Rates Have Been Altered or Not

One possible source for the different reaction patterns between the two economies could be that the markets react differently depending on whether monetary policy rates are changed or not. In this regard, monetary policy moves usually take place when market uncertainty can be expected to be higher than normal, such as risks of very low inflation or outright deflation,[11] or when there is uncertainty regarding an expected future strengthening of economic activity.[12] Furthermore, some interest rate moves take place during extreme market conditions. One example was the joint interest rate reduction of 50 basis points by the ECB and the Federal Reserve in the aftermath of the September 11 terrorist attack. Using daily data, Wilhelmsen and Zaghini (2005) find less predictability—the latter measured as the standard deviation in money market rates—when a modification in the official policy rate is decided on, compared with days when the monetary policy authority does not change the official rate. This pattern holds true for all fourteen economies included in their study.

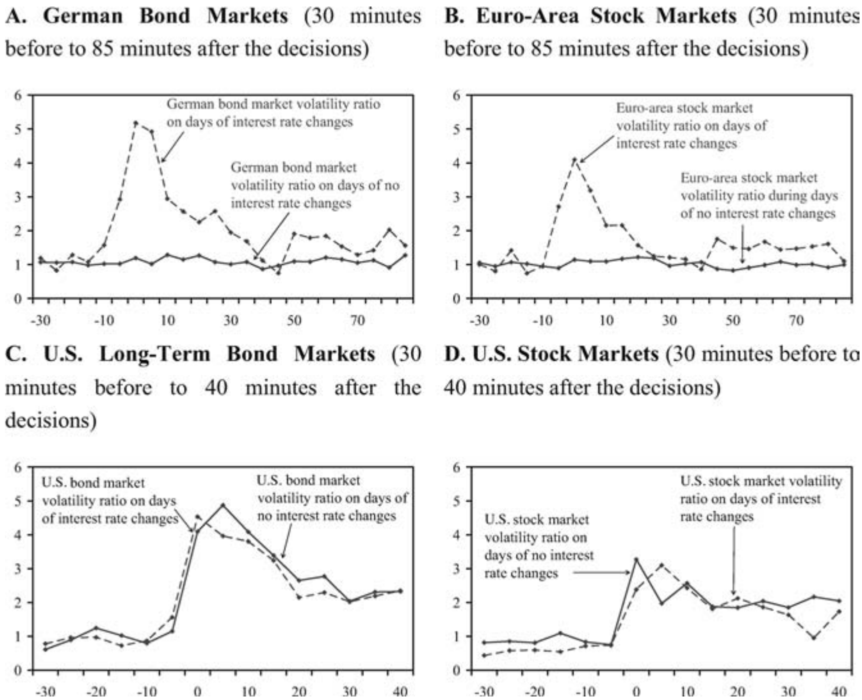
Figures 6A–6D decompose the volatility pattern between monetary policy events when policy rates are adjusted and when they remained unchanged. As seen in figures 6A and 6B, the elevated volatility in euro-area stock and bond markets during monetary policy announcements seems to be related to the periods when the ECB decided to change rates. In contrast, monetary policy decisions by the Federal Reserve induce elevated stock and bond market volatility independent of the outcome (see figures 6C and 6D).

One possible explanation for the different pattern of behavior across the two markets can be related to an asymmetry in the monetary policy surprises, i.e., that they are higher in magnitude when the ECB changes rates compared with no change events. Table 5 summarizes the mean and the standard deviation of the surprises conditional on whether rates have been altered or not. Overall, the mean

[11] An example of this was the 25-basis-point rate reduction by the Federal Reserve in June 2003. The accompanying statement justified the decision: "The Committee perceives that the upside and downside risks to the attainment of sustainable growth for the next few quarters are roughly equal. In contrast, the probability, though minor, of an unwelcome substantial fall in inflation exceeds that of a pickup in inflation from its already low level."

[12] An example of this was the increase of 25 basis points by the ECB in December 2005. The accompanying introductory statement explained why: "On the basis of our regular economic and monetary analyses, we have decided to increase the key ECB interest rates by 25 basis points, after two and a half years of maintaining rates at historically low levels. Looking ahead, on the external side, ongoing growth in global demand should support euro area exports, while on the domestic side, investment should benefit from continued favourable financing conditions and the robust growth of corporate earnings."

Figure 6. Volatility Ratios on Days with and Days without Changes in Monetary Policy Rates



of the (absolute) surprises is somewhat higher in both economies (and for both categories of surprises) when rates were changed compared with those meetings when they remained unchanged. However, the difference is particularly pronounced for the computed target surprise of the ECB, which could partly explain why asset-price volatility in the euro area is higher when policy rates are adjusted compared with periods when policy rates are left unchanged.

To examine the asymmetric issue further, a slight modification of the regression setup in equation (3) is used:

$$\Delta Volratio_{t-30,t+5} = \alpha_1 + \alpha_2 D + \beta_{1,t} X + \beta_{2,t} DX + \varepsilon_t, \qquad (4)$$

where D is a dummy variable which takes on a value of 1 when interest rates are changed, and a value of 0 if they are unchanged. The matrix X corresponds to the independent variables (i.e., the

Table 5. Summary Statistics of the Monetary Policy Surprises

	ECB		Federal Reserve	
	Target Surprise	**Path Surprise**	**Target Surprise**	**Path Surprise**
Mean of the Absolute Surprises				
Total Sample	3.0	1.0	2.5	3.4
When Rates Were Left Unchanged	1.5	0.6	0.6	2.8
When Rates Were Changed	13.0	1.4	4.0	4.0
Standard Deviation of the Absolute Surprises				
Total Sample	5.6	1.4	5.6	3.2
When Rates Were Left Unchanged	3.2	0.5	1.0	2.6
When Rates Were Changed	7.7	1.9	7.1	3.5

absolute values of the target and path surprises). Equation (4) has the following implications:

Mean volatility when $D = 0$ (i.e., monetary policy rates are unchanged):

$$E(\Delta Volratio|D = 0, X) = \alpha_1 + \beta_1 X. \quad (5)$$

Mean volatility when $D = 1$ (i.e., monetary policy rates are altered):

$$E(\Delta Volratio|D = 1, X) = (\alpha_1 + \alpha_2) + (\beta_1 + \beta_2)X. \quad (6)$$

Four different possibilities can be tested using this setup:

(i) $\alpha_1 = \alpha_2$ and/or $\beta_1 = \beta_2$; the two regressions are the same.

(ii) $\alpha_1 \neq \alpha_2$ and/or $\beta_1 = \beta_2$; the two regressions differ in the intercept.

Table 6. Regression Results Conditional on Altered Monetary Policy Rates

Dependent Variable $\Delta Volratio_{t-30,t}$	**Constant**	**Constant $\vert D = 1$**	$\boldsymbol{Abs(TS)}$	$\boldsymbol{Abs(TS)}$ $\boldsymbol{\vert D = 1}$	$\boldsymbol{Abs(PS)}$	$\boldsymbol{Abs(PS)}$ $\boldsymbol{\vert D = 1}$
German Bond	0.00	−0.36	0.09*	0.25**		
Markets	(0.15)	(1.58)	(0.05)	(0.11)		
Euro-Area Stock	−0.39**	0.29	0.03	0.00	0.56***	0.43*
Markets	(0.19)	(1.00)	(0.06)	(0.08)	(0.20)	(0.26)
U.S. Bond	1.83	−1.40			0.60***	0.24
Markets	(1.14)	(1.35)			(0.22)	(0.34)
U.S. Stock	0.81	−0.40			0.59***	−0.20
Markets	(0.88)	(0.99)			(0.19)	(0.19)

Notes: The regression specification follows the one specified in equation (4) to test whether price sensitivity differs during periods when the central banks change policy rates. Newey-West heteroskedasticity-consistent standard errors are in parentheses. *, **, and *** denote significance at the 10, 5, and 1 percent levels, respectively.

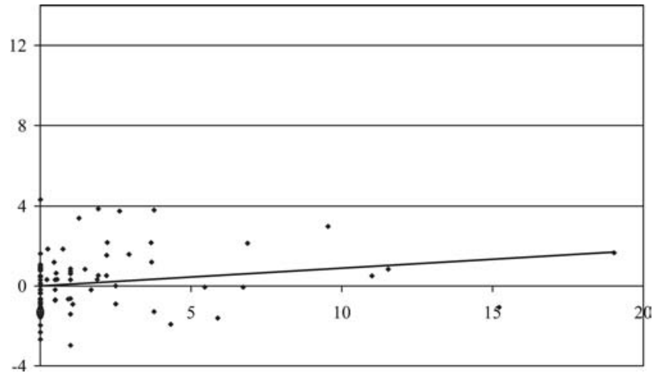
(iii) $\alpha_1 = \alpha_2$ and/or $\beta_1 \neq \beta_2$; the two regressions have the same intercept but different slopes.

(iv) $\alpha_1 \neq \alpha_2$ and/or $\beta_1 \neq \beta_2$; the two regressions have different intercepts and different slopes.

Thus, a significantly positive α_2 coefficient suggests that volatility on average is higher when monetary policy rates are altered compared with periods when rates are left unchanged. In the same vein, a significant positive coefficient of β_2 implies stronger asset-price sensitivity when monetary policy rates are altered compared with periods when rates are left unchanged. Of particular interest is to test the significance of α_2 and/or β_2 for the German bond markets and the euro-area stock markets. This could shed further light on the factors driving the elevated volatility following alterations of the ECB's monetary policy rates, as shown in figure 6. Table 6 outlines the results of the regressions after dropping the non-significant variables from equation (3).

The table reveals that asset-price sensitivity is not linear for the German bond markets and the euro-area stock markets. Instead, the volatility pattern is different depending on if policy rates have been

Figure 7. Changes in German Bond Volatility Ratio (y-axis) and the ECB Monetary Policy Target Surprise (x-axis): Sample Includes Only Observations when the ECB Left Monetary Policy Rates *Unchanged* (April 1999–May 2006)



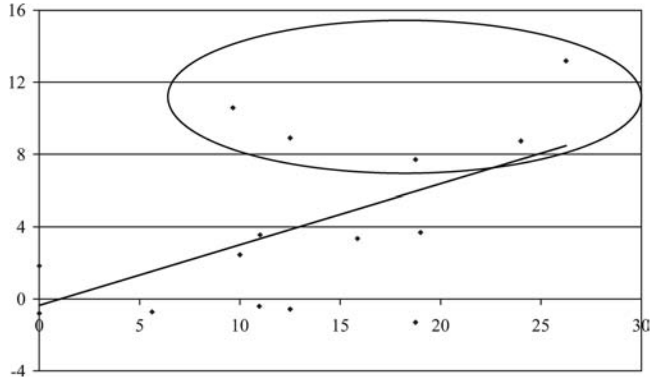
altered or not. For the German bond market, the null hypothesis of equal slope coefficient can be rejected at the 5 percent level. For the euro-area stock markets, the null hypothesis of equal slope coefficient can be also be rejected, but only at the 10 percent level. As regards the United States, no differences in the asset-price reaction following either scenario can be detected.

Figures 7 and 8 illustrate the differences in asset-price pattern for the German bond market volatility ratio by scatter-plotting the volatility ratios against the target surprises. The figures suggest that intraday volatility tends to be of larger magnitude (see figure 8) when interest rates are changed than when they are not changed (see figure 7), even when the surprises are of the same magnitudes. Comments from the financial press after the interest rate decisions highlighted in figure 8 seem to suggest that the interest rate decisions took the markets by surprise during these occasions; see table 7.

5. Concluding Remarks

Monetary policy decisions and the expected path of future policy rates strongly influence asset prices. Among the worlds' leading central banks, monetary policy actions by the Federal Reserve and the

Figure 8. Changes in German Bond Volatility Ratio (y-axis) and the ECB Monetary Policy Target Surprise (x-axis): Sample Includes Only Observations when the ECB *Altered* Monetary Policy Rates (April 1999–May 2006)



ECB are particularly monitored among investors, as they control short-term interest rates in the two major economies. This paper tries to shed some light on the link between monetary policy decisions and asset-price reactions. Using long-time series of intraday data, U.S. and euro-area bond and stock market intraday volatility patterns surrounding monetary policy decisions by the two central banks are derived. Overall, both the ECB and the Federal Reserve decisions induce an upsurge in intraday volatility on their respective bond and stock markets. The reactions of U.S. financial markets following the Federal Reserve's decisions are more pronounced compared with the reaction the ECB exerts on the German bond markets and the euro-area stock markets. Although this paper provides some tentative explanations that partly explain this discrepancy between the two markets, their decoupling patterns still remain a puzzle.

As a next step, monetary policy target and path surprises are used as explanatory variables when explaining these upsurges in volatility. Monetary policy surprises are suitable candidates for this purpose, as only new news should in theory affect asset prices. The paper finds that monetary policy target surprises by the ECB significantly induce higher than normal volatility in the German bond

Table 7. Financial Market Comments to ECB Monetary Policy Decisions

Date	Interest Rate Move	Target Surprise	Comment
June 8, 2000	+50 bp	26.25	*Financial Times* (June 9, 2000): "The ECB rate rise demonstrated the bank is not afraid of making decisions that surprise the markets. . . . Most investors expected rates to go up by 25 basis points and did not price in a 50 basis points rise. . . . German 10-year bund prices advanced despite the surprisingly aggressive rise in interest rates while the short-dated bonds sold off."
May 10, 2001	−25 bp	−24	*Financial Times* (May 11, 2001): "Interest rates fall across Europe. . . . Markets were stunned by the ECB's 0.25 percentage point reduction in its main interest rate to 4.5 per cent. It was the ECB's first cut for more than two years and caught investors unprepared."
Oct. 5, 2000	+25 bp	18.75	*Financial Times* (October 6, 2000): "The biggest surprise in the government bond markets yesterday was the European Central Bank's decision to raise interest rates by 25 basis points to 4.75 per cent, with prices on government bonds falling in response. . . . After the initial shock wore off, bond prices recovered."

(continued)

Table 7. (Continued)

Date	Interest Rate Move	Target Surprise	Comment
March 6, 2003	−25 bp	12.5	*Financial Times* (March 7, 2003): "Short-dated eurozone government bond prices recovered their early losses yesterday, despite the European Central Bank's decision to lower interest rates by a quarter rather than a half point. The ECB cut rates to 2.5 per cent, but comments by Wim Duisenberg, ECB president, suggested further easing was on the cards."
Dec. 5, 2002	−50 bp	−9.6	*Financial Times* (December 6, 2002): "European government bond trading was dominated yesterday by interest rate decisions, notably the European Central Bank's half-point cut to 2.75 per cent. . . . Eurozone bonds initially rose on the ECB's announcement of its first reduction in rates for more than a year."

markets. In addition, path surprises by the Federal Reserve have, on average, a larger influence on U.S. bond and stock market volatility compared with target surprises.

When decomposing the asset-price reaction based on whether monetary policy rates have been altered or not, the level of intraday volatility of the German bond markets and the euro-area stock markets is found to be higher when interest rates are changed. This can probably be linked to two factors. First, monetary policy surprises are, on average, of a larger magnitude when the ECB decides to change rates compared with meetings which resulted in no change. Second, there is a non-linear asset volatility price sensitivity—which is particularly pronounced for the German bond markets—in that bond markets react significantly stronger to a given target surprise by the ECB when there has been a change in the official rate compared with periods when the policy rates have not been altered.

Building on this study, a key direction for future research would be to find further evidence of factors that could explain the pronounced asset-price reaction in the U.S. financial markets following interest rate decisions by the Federal Reserve, compared with the more muted feedback on euro-area asset prices surrounding the ECB's monetary policy decisions.

Appendix

The volatility measure used as the dependent variable in regressions (3) and (4) is defined as the ratio between volatility on monetary policy days and volatility on the same weekdays and hours but when no monetary policy decisions are taking place. More specifically, let $k = 1, 2 \ldots K$ be the days of monetary policy decisions and $d = 1, 2 \ldots D$ be the same weekdays, but when no monetary policy decisions are taking place. The intraday change in the volatility ratio for asset i on a monetary policy decision day k is then calculated as

$$\Delta Volratio^{i,k}_{t-30,t} = \left(\frac{abs(R^{i,k}_{t=0})}{\frac{1}{D}\sum\limits_{d=1}^{D} abs(R^{i,d}_{t=0})} - \frac{abs(R^{i,k}_{t=-30})}{\frac{1}{D}\sum\limits_{d=1}^{D} abs(R^{i,d}_{t=-30})} \right).$$

R represents the five-minute log-return.

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The Geography of International Portfolio Flows, International CAPM, and the Role of Monetary Policy Frameworks*

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Using bilateral data on international equity and bond flows, we find that (i) the prediction of the International Capital Asset Pricing Model is partially met and that global equity markets might be more integrated than global bond markets, and (ii) asset allocators engage in trend-chasing activities, particularly in bond markets. Moreover, over the turbulent 1998–2001 period characterized by an equity bubble and the subsequent burst, we find evidence that investors preferred portfolio assets of countries where the central bank gave relative importance to money. As for EMU, once controlling for diversification benefits and the elimination of the exchange rate risk, we show that cross-border portfolio flows among euro-area countries have increased due to the catalyst effect of EMU. Countries' shares in the world market portfolio, home bias, initial degree of misallocation across countries, past returns, diversification benefits, and EMU can explain 35–40 percent of the total variation in equity and bond asset flows.

JEL Codes: C13, C21, F37, G11.

1. Introduction

The International Capital Asset Pricing Model (IntCAPM) suggests that international investors should hold assets of each country in

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proportion to the country's share in the world market portfolio.[1] This implies that all countries, in a world without transaction and information costs, would hold the same portfolio and would diversify their investment in other countries in proportion to the size of their financial markets. In this respect, global indices such as the popular Morgan Stanley Capital International (MCSI) All Country World Index (ACWI), Datastream Global index, and Standard and Poor's (S&P's) Global index are widely used by investors as their performance benchmarks for the global asset portion of their equity portfolio. The first aim of this paper is to examine whether countries allocate money according to the simple prediction of the IntCAPM. We also assess the empirical relevance of the IntCAPM for the bond market. In order to carry out this test, we employ the Lehman Brothers Multiverse index released in 2001 as the benchmark for the global bond market.

It is useful to point out that recent studies have looked at the contemporaneous link between the actual weight of country j in fund i's equity portfolio and the optimal weight suggested by the IntCAPM for emerging markets (Gelos and Wei 2005). We instead aim at investigating whether portfolio flows (divided by the size of the investors) and, therefore, the global reallocation of portfolio capital across twenty-three developed countries and seven emerging-market economies are functions of the optimal weights at the beginning of the period as suggested by the IntCAPM.

In order to carry out such a study, we construct a database on bilateral cross-border equity and bond flows for thirty countries covering in 2001 80 percent of world GDP, 84 percent of world international investment in equity portfolios, and 71 percent of world international investment in bonds and notes portfolios. Therefore, the thirty countries of the sample and the cross-section of 870 bilateral observations encompass all important international investment decisions (excluding official investments by monetary authorities).

Specifically, we construct measures of bilateral net asset flows of equities and bonds mainly on the basis of the International Monetary

[1]The International Capital Asset Pricing Model and the Intertemporal Asset Pricing Model are often referred to using the same label: I-CAPM. We use IntCAPM to avoid confusion.

Fund (IMF) Coordinated Portfolio Investment Survey (CPIS) database, which reports bilateral holdings at end-1997 and end-2001. We define net asset flows of equities and bonds as the purchases minus the sales of country k's equities and bonds by citizens of country c. The considered period was characterized by the sharp rise in cross-border capital flows globally, the increased percentage of household savings invested in capital markets, the boom and bust of the equity bubble, and the establishment of European Economic and Monetary Union (EMU) in January 1999. Looking at cumulated portfolio net asset flows over the four-year period 1998–2001 has the advantage of abstracting from short-run variations in international portfolio flows, which could be due to unexpected economic news and cyclical developments, as well as phenomena which are difficult to pin down.

The second aim of the paper is to assess whether, during this turbulent period for asset markets, central banks' monetary policy frameworks across countries influenced the geography and size of international capital flows.[2] As a consequence of the asset-price shocks, international investors might have preferred to reallocate their portfolio assets toward countries that gave importance to specific characteristics of monetary policy frameworks. Therefore, we employ the results of a survey commissioned and coordinated by the Bank of England in 1998 aiming at measuring several key characteristics of the monetary frameworks consistently across ninety-four central banks (Mahadeva and Sterne 2000). Moreover, given the new monetary policy framework, which came to light in Europe in January 1999, we also look and control for the potential impact of EMU on global portfolio flows as found by Lane (2006) for fixed-income investments and by De Santis and Gérard (2009) for both equity and fixed-income investments.

International portfolio flows have skyrocketed in the last fifteen years, and a large number of studies have tried to explain their

[2]A large body of the literature pointed to the importance of institutional characteristics of the monetary policy framework—such as central banks' independence, accountability, and transparency—to control inflationary expectations and safeguard financial stability (i.e., Rogoff 1985; Alesina and Summers 1993). Several measures of central banking independence were also constructed and used to study the impact on inflation (Grilli, Masciandaro, and Tabellini 1991; Cukierman 1992; Jácome and Vázquez 2005).

determinants. However, data limitations have meant that these contributions focused on country aggregates of net equity and debt flows (De Santis and Lührmann 2009), on country aggregates of inflows of equity capital—foreign direct investment plus portfolio equity securities—(Alfaro, Kalemli-Ozcan, and Volosovych 2007), or have only considered a single source country, most often the United States being the recipient or the source of the investment (Bohn and Tesar 1996; Brennan and Cao 1997; Coval and Moskowitz 1999; Froot, O'Connell, and Seasholes 2001; Huberman 2001; Ahearne, Griever, and Warnock 2004). Portes and Rey (2005) is the only study that looks at bilateral cross-border equity flows between fourteen countries pointing to the role played by information costs. De Santis and Gérard (2009) is the only study looking at the determinants of bilateral changes in portfolio country weights in both equity securities and fixed income for a panel of thirty countries pointing to the role played by the non-linear fully hedged diversification benefits, the initial degree of misallocation, and the establishment of EMU. Another branch of the literature has studied the determinants of bilateral bank and portfolio holdings using empirical methods borrowed from the traditional gravity models of international goods trade (Faruqee, Li, and Yan 2004; Lane 2006; Aviat and Coeurdacier 2007; Lane and Milesi-Ferretti 2008; Papaioannou 2009).

Our main contribution to the literature is that we find clear evidence that portfolio asset flows are influenced positively by the relative size of the recipient countries' financial markets. The predictions of the IntCAPM are only partially met, as the estimated coefficient on the benchmarks is less than unity: 0.4 for the equity portfolio and 0.2 for the bond portfolio. Moreover, we find that asset allocators engage in trend-chasing activities, particularly in bond markets. These results do not change when controlling for home bias and the initial degree of underweight, which enters non-linearly, therefore potentially proxying for initial direct and indirect costs.

We also find that, during the turbulent 1998–2001 period, international investors in both equity and fixed-income markets had a tendency to purchase assets issued by countries whose monetary authorities gave importance to money.

We estimate on a 95 percent confidence interval the potential catalyst effect of the euro within the euro area to amount to USD 22–47 billion in equity securities and USD 32–76 billion in bonds and notes, which implies that EMU might have enhanced risk sharing among euro-area member states. The catalyst effect of the euro is estimated after controlling for the elimination of the exchange rate risk among euro-area member states and the effect of being a member of the European Union (EU). EMU boosted the cross-border investment activity among euro-area member states due to the removal of intra-area currency-matching rules, the sharing of common trading platforms, and the cross-border merger of the Amsterdam, Brussels, Lisbon, and Paris exchanges (Euronext).

The proportion of the total variation explained by our empirical models amounts to 35–40 percent for both equity and bond flows. This is a valuable result given that we look at the geography of international portfolio flows during a very difficult period for asset management.

The remainder of the paper is organized as follows. Section 2 discusses the key ideas. Section 3 describes the databases used for the analysis. Section 4 outlines the empirical approach and tests the IntCAPM. Section 5 assesses the role of monetary policy frameworks and estimates the potential impact of EMU on portfolio flows. Section 6 reports how robust the model specifications are when controlling for other variables, which could potentially affect portfolio flows. Section 7 concludes.

2. A Simple Theory

2.1 The IntCAPM

Consider a representative investor from a generic country c and let γ_c denote the investor's degree of risk aversion. Also, indicate with $\boldsymbol{\mu}_c$ the $(N \times 1)$-vector of expected returns in excess of the risk-free rate on the N risky assets, and with Σ_c the expected $(N \times N)$-covariance matrix for the risky assets, where the subscript c indicates that returns are measured in the currency of country c. If the investor faces no constraints on foreign holdings and financial markets are perfectly integrated, mean-variance optimization implies the following portfolio allocation:

$$\boldsymbol{w}^*_{c,t} = \frac{1}{\gamma_c} \Sigma^{-1}_{c,t} \boldsymbol{\mu}_{c,t},$$

where $\boldsymbol{w}_{c,t}^{*}$ is the $(N \times 1)$-vector of optimal weights for the N risky assets.

The optimal weights are not observable. However, in a fully integrated world where purchasing power parity (PPP) holds, Solnik (1974) and Sercu (1980) show that the international version of the simple CAPM of Sharpe (1964) and Lintner (1965) holds: the market equilibrium is achieved when all investors hold the world market portfolio, where each country portfolio is weighted by its market capitalization. Therefore, an observable estimate of the optimal weight invested in each country k is equal to that country k's market capitalization weight in the world index portfolio, $w_{k,97}^{Bench}$:

$$\boldsymbol{w}_{c,t}^{*} = \boldsymbol{w}_{k,t}^{Bench}.$$

There exist several standard benchmarks for the equity portfolio, such as the popular MCSI ACWI, Datastream Global index, and S&P's Global index, as they provide consistent data, have sufficiently long price history, and are widely used by global investors. We use the Datastream Global index and compare the results with S&P's Global index, as both include the country coverage used in this study.

To our knowledge, a similar benchmark for the bond portfolio for such a number of countries was never used due to difficulty in compiling countries' bond market capitalization at market value. In January 2001, Lehman Brothers launched a new index (i.e., Multiverse index), which provides a broad-based measure of the international fixed-income bond market, with index history dating back to January 1999. Multiverse index provides information on the overall status of the global debt asset class and offers a means to compare the entire global debt asset class across countries.

Table 1 provides the estimated market shares across countries in both equity and bond markets, which will then be used to test the IntCAPM. The first and second columns report the equity portfolio weights computed using the market value of the Thomson Datastream and S&P's Global indices, respectively. The last two columns report, respectively, the bond portfolio weights computed using the market value of the Lehman Brothers Multiverse index and the outstanding amount as reported by the Bank for International Settlements (BIS). The equity portfolio weights of Datastream and S&P

Table 1. Portfolio Weights (percentage share)

	Equity Portfolio		Bond Portfolio	
	Datastream Global Index End-97	S&P Global Index End-97	Lehman Bros. Multiverse Index End-98	BIS End-97
Argentina	0.31	0.26	0.39	0.16
Australia	1.35	1.28	0.55	0.56
Austria	0.17	0.15	0.72	0.64
Belgium	0.64	0.59	1.96	1.43
Bermuda	—	0.01	0.02	0.01
Canada	2.47	2.46	2.56	2.07
Chile	0.29	0.31	0.03	0.19
Denmark	0.40	0.41	0.88	1.26
Finland	0.35	0.32	0.83	0.26
France	3.32	2.92	6.12	4.10
Germany	4.18	3.57	6.06	7.76
Iceland	—	0.01	0.00	0.02
Indonesia	0.12	0.13	0.04	0.29
Ireland	0.24	0.21	0.25	0.12
Israel	0.13	0.20	0.01	0.43
Italy	1.80	1.49	5.65	5.46
Japan	12.51	9.59	7.18	16.37
Korea	0.14	0.20	0.17	0.37
Malaysia	0.36	0.40	0.01	0.18
Netherlands	2.75	2.03	2.14	1.45
New Zealand	0.17	0.13	0.13	0.07
Norway	0.30	0.29	0.18	0.26
Portugal	0.30	0.17	0.32	0.24
Singapore	0.53	0.46	0.11	0.07
Spain	1.25	1.26	2.48	1.31
Sweden	1.10	1.18	1.09	1.03
Thailand	0.09	0.10	0.01	0.05
United Kingdom	10.50	8.64	4.74	2.78
United States	44.90	48.92	53.57	48.02
Venezuela	0.04	0.06	0.11	0.11
Subtotal	90.69	87.73	98.31	97.06
Total (USD billion)	17,634	23,116	10,355	19,054

Note: This table presents the sample descriptive statistics for portfolio weights used to test the validity of the IntCAPM.

are very similar. Some small differences can be identified for the bond portfolio weights mainly due to the fact that the Lehman Brothers Multiverse index is evaluated at market value, while the BIS bond outstanding is at face value.

The computations reported in table 1 indicate that according to the IntCAPM, almost 50 percent of world portfolio should be invested in U.S. securities. As for the euro area (e.g., Luxembourg and Greece), approximately 14 percent of world portfolio should be invested in euro-area equity securities and 25 percent in euro-area bonds.

We will report the empirical results using Datastream weights for equity portfolio and Lehman Brothers weights for bond portfolio.[3] It is useful to point out that all the results remain invariant when using, respectively, S&P weights and BIS weights.

2.2 The Role of Central Banks

There is no doubt that capital flows are affected by the institutions of a country (Alfaro, Kalemli-Ozcan, and Volosovych 2007; Coeurdacier, De Santis, and Aviat 2009; De Santis and Lührmann 2009). However, there is no empirical study looking at the role of central banking institutional setting. Surely, monetary policy influences the decisions of international investors, but less obvious is understanding why specific central bank monetary policy characteristics should affect international investment decisions. Moreover, at the turn of the century, as a consequence of the asset-price shocks, international investors might have preferred to reallocate their portfolio assets toward countries that gave importance to specific characteristics of monetary policy frameworks.

Therefore, we employ the results of a comprehensive survey commissioned by the Bank of England in 1998, because it aimed at measuring consistently the diversity in monetary frameworks across ninety-four central banks with a coverage of characteristics that stretched beyond previous studies (Mahadeva and Sterne 2000). Specifically, we look at the following characteristics: (i) short- and

[3]The employed portfolio weights for Bermuda and Iceland amount to 0.01 percent as indicated by S&P's Global index.

medium-term policy focus—inflation, money, exchange rate, and discretionary policy; (ii) institutional characteristics—independence, accountability, and transparency of policy explanations; and (iii) structural characteristics—importance given to financial stability in the setting of monetary policy instruments.

Central bank independency is defined by a range of characteristics covering legal objectives, goal, instruments, finance of the government deficit, and term of office of the governor.

The measure of *accountability* was constructed by assessing how far the central bank has a legal or informal responsibility to explain and defend its policies to government and parliament and to involve parliament in monetary policy decisions. Therefore, the measure relates to accountability to a specific target as well as to governmental and parliamentary monitoring of the central bank.

The measure of *policy explanations* is defined by the effort made by the central bank in explaining policy decisions, assessment of the economy, and forecasts and forward-looking analysis. It can be interpreted as one aspect of transparency in that deeper explanations of policy, which allow us to understand its goal and the means by which policymakers react to changes in economic conditions, is one important manifestation of higher degree of transparency.

As for the measures of *monetary policy objectives*, they are defined and classified by the exchange rate, money growth, and inflation dimensions, rather than just one dimension, and give the degree to which a country's policy focused on a particular objective. Therefore, the survey is constructed to avoid a 100 percent commitment to a single objective, as in most cases definitions that focus on the explicit variable targeted may not fully capture policy preferences. The general measure of discretion is a non-linear combination of the scores for exchange rate focus, money focus, and inflation focus.

Finally, the *importance of financial stability* in the monetary framework is defined by various financial stability issues, such as the volatility of asset prices, domestic and overseas financial sector insolvency, and credit rationing.

The eight indices range between 0 and 100, where a high score implies more independence, more accountability of central bank to government, more policy explanations to those outside the central bank, and a higher degree of importance given to policy objectives and financial stability issues (see table 2).[4]

Some of these indices are also strongly correlated (see table 3). The focus on the exchange rate is strongly correlated with the focus on inflation and money, with the transparency index, and with the importance given to financial stability; in turn, the focus on money is strongly correlated with the importance of financial stability.

Interestingly, independence and accountability are negatively correlated (−20 percent), which implies that explaining and defending monetary policies to government and parliament and the involvement of parliament in monetary policy decisions might be partly seen by central banks as an infringement on their independence.

2.3 The Role of EMU

The establishment of EMU in January 1999 was a fundamental institutional change in the world economy that has affected the direction and the magnitude of global portfolio flows. Lane (2006) and De Santis and Gérard (2009) uncover evidence of euro-area investors having assigned a higher weight to portfolio investment in euro-area countries, which implies that EMU has facilitated portfolio market access, enhancing risk sharing and regional financial integration. EMU boosted the cross-border investment activity among euro-area member states due to the removal of intra-area currency-matching rules, the sharing of common trading platforms (such as the MTS model composed of several national European markets for trading fixed-income securities),[5] and the cross-border merger of the Amsterdam, Brussels, Lisbon, and Paris exchanges (Euronext).

In most countries, portfolio funds are often subject to some form of restriction on the level of their non-domestic investment.

[4]For a comprehensive analysis on the construction of all the indices measuring the monetary policy frameworks across countries, refer to chapter 4 of Mahadeva and Sterne (2000). Bermuda and Venezuela are not included in the survey. Therefore, we use the U.S. characteristics for Bermuda, as the Bermuda dollar is at par with the U.S. dollar, and we use the Uruguay characteristics for Venezuela given the similarities of the monetary policy frameworks of these two countries (see Jácome and Vázquez 2005).

[5]Detailed information can be found at http://www.mtsgroup.org/.

Table 2. Sample Descriptive Statistics for the Characteristics of the Monetary Policy Framework

	Policy Focus				Institutional Factors			Structural Factor
	Inflation	Money	Exchange Rate	Discretion	Independence	Accountability	Transparency	Financial Stability
Argentina	0	0	100	0	79	100	53	58
Australia	94	0	0	6	73	83	78	8
Austria	0	0	88	13	68	67	27	17
Belgium	0	0	94	6	77	33	68	8
Bermuda	19	25	0	84	92	83	95	33
Canada	88	0	6	16	91	100	79	33
Chile	88	0	31	28	93	17	83	17
Denmark	0	0	94	6	88	75	70	0
Finland	56	0	63	66	91	92	74	8
France	40	46	58	84	90	83	53	50
Germany	19	88	13	29	96	17	70	33
Iceland	19	0	75	34	59	92	65	8
Indonesia	50	63	6	66	56	83	83	83
Ireland	19	0	75	34	87	83	78	8
Israel	88	0	13	19	66	100	68	33
Italy	44	44	50	94	88	58	81	33
Japan	50	0	0	50	93	0	89	50
Korea	63	75	6	59	73	83	88	58

(continued)

Table 2. (Continued)

	Policy Focus				Institutional Factors			Structural Factor
	Inflation	**Money**	**Exchange Rate**	**Discretion**	**Independence**	**Accountability**	**Transparency**	**Financial Stability**
Malaysia	44	0	38	75	85	83	71	67
Netherlands	0	0	88	13	91	83	79	8
New Zealand	94	0	0	6	89	100	92	8
Norway	0	0	69	31	57	50	89	17
Portugal	6	0	75	28	85	83	78	33
Singapore	19	0	56	53	90	25	49	17
Spain	56	0	63	66	80	83	59	33
Sweden	100	0	13	6	97	83	95	42
Thailand	31	6	6	75	82	50	67	83
United Kingdom	100	0	0	0	77	100	94	16
United States	19	25	0	84	92	83	95	33
Venezuela	25	0	88	25	70	83	4	17

Notes: This table presents the sample descriptive statistics for the characteristics of the monetary policy framework (see Mahadeva and Sterne 2000, pp. 141–62). The eight indices range between 0 and 100, where a high score implies more independence, more accountability to governments, more policy explanations to those outside the central bank, and a higher degree of importance given to policy objectives and financial stability issues.

Table 3. Correlation Matrix of the State of Development, Quality of the Institutions, and Monetary Frameworks Variables

	Development			Quality of the Institutions				Monetary Policy Frameworks							
	GP	BC	RD	CL	LP	IC	PC	INF	MON	FX	DIS	IND	ACC	TRA	FS
GP	1.00														
BC	0.29	1.00													
RD	0.66	0.32	1.00												
CL	−0.65	−0.09	−0.45	1.00											
LP	0.87	0.31	0.67	−0.65	1.00										
IC	0.78	0.08	0.42	−0.54	0.79	1.00									
PC	0.71	0.02	0.53	−0.58	0.85	0.77	1.00								
INF	−0.17	−0.08	0.18	−0.01	−0.01	−0.18	0.15	1.00							
MON	−0.10	0.03	0.10	0.17	−0.17	−0.27	−0.35	−0.05	1.00						
FX	0.08	−0.44	−0.24	−0.07	0.01	0.30	0.01	−0.68	−0.32	1.00					
DIS	−0.15	0.32	−0.09	0.30	−0.20	−0.22	−0.37	−0.12	0.44	−0.21	1.00				
IND	0.21	0.39	0.29	−0.24	0.37	0.40	0.37	0.12	0.06	−0.21	0.16	1.00			
ACC	−0.10	−0.37	−0.02	−0.19	−0.04	−0.23	0.08	0.26	−0.19	0.03	−0.12	−0.20	1.00		
TRA	0.28	0.37	0.34	−0.31	0.31	0.12	0.27	0.37	0.12	−0.60	0.08	0.28	0.02	1.00	
FS	−0.58	0.23	−0.26	0.56	−0.61	−0.70	−0.72	0.09	0.42	−0.38	0.49	−0.02	−0.05	0.07	1.00

Notes: The variables of this table are labeled as follows: GP = Countries' GDP per capita minus the GDP per capita of Norway; BC = Bank credit to the private sector/GDP minus world share; RD = R&D expenditure/GDP minus world share; CL = Civil liberties index; LP = La Porta index; IC = ICRG index; PC = Perceived corruption index; INF = Inflation focus index; MON = Money focus index; FX = Exchange rate focus index; DIS = Discretion focus index; IND = Independence index; ACC = Accountability index; TRA = Transparency index; FS = Role of financial stability index.

Currency-matching rules for portfolio funds, for example, are set to ensure that foreign currency risk is reduced. Since the introduction of the euro in January 1999, the intra-euro-area currency-matching rule has shifted from national currencies to the euro. The resulting greater flexibility allowed individual euro-area country portfolios to secure better diversification of investment risk by purchasing more non-domestic euro-area assets.[6]

To control for the effect of EMU on global capital flows as well as to measure its average impact, we include two sets of binary variables. First we include a dummy which takes the value of 1 if the country receiving the investment belongs to the EMU. The coefficient of this dummy measures the average portfolio asset flow into individual EMU countries for all investors. However, the effect of the single currency may be more pronounced on the investment decisions of investor-residents in the euro area. To control for this differential effect, we include a dummy variable which takes the value of 1 when both investing and receiving countries belong to the EMU. The coefficient of this dummy measures the average portfolio asset flow into individual euro-area countries for all euro-area investors that comes *in addition to* the average flow observed for all investors. Accordingly, it quantifies the average financial integration effect of EMU for the individual euro-area member state.[7]

[6]For example, Europe's life insurance companies could not hold more than 20 percent of their assets in foreign currencies unless they were matched by liabilities denominated in the same currency. As the vast majority of those liabilities were denominated in national currency, so were most of the assets. Quantitative restrictions are also typical for pension funds. For a description of the restrictions in the EU before EMU, see International Monetary Fund (1997, table 63, p. 213).

[7]A further complication comes from the role of the London market as a major intermediary of foreign investments from and to the rest of the world. Due to the large size and higher sophistication of the London markets, many investors choose to make their foreign investments via the United Kingdom. For example, a Japanese investor may choose to select a British investment manager to invest in euro-area equities and bonds. The IMF data on portfolio holdings report an accurate country breakdown of bilateral investment, which tries to identify the residence of the issuer. Nevertheless, since the city of London is a key European player, we control for that by including two additional dummies. The first dummy takes a value of 1 if the receiving country is the United Kingdom. A second dummy takes the value of 1 if the investing country belongs to the EMU and the receiving country is the United Kingdom.

3. Data: The Geography of International Portfolio Flows

The IMF Coordinated Portfolio Investment Survey (CPIS) database reports the portfolio positions of international investors, excluding the official holdings of monetary authorities disaggregated by regions and instruments. More specifically, the CPIS data set provides a geographical breakdown of international portfolio holdings disaggregated by three instruments—equity securities, long-term debt securities, and short-term debt securities—and includes virtually all major international investment, excluding foreign direct investment. An additional advantage of this data set is the consistency of the compilation criteria:

- Participants undertake a benchmark portfolio asset survey at the same time.
- Participants follow definitions and classifications that are mutually consistent by following the methodology set out in the fifth edition of the IMF *Balance of Payments Manual*.
- All participants provide a breakdown of their stock of portfolio investment assets by the country of residency of the non-resident issuer.

There are also several issues related to the CPIS database: (i) data on the rather poor countries is missing; (ii) coverage is incomplete due to lack of important portfolio holders, such as Middle East countries and China; (iii) several transactions are reported as confidential for offshore financial centers and emerging markets; (iv) liabilities are bigger than assets, pointing toward underreporting; and (v) collection methods differ from country to country, which is an issue particularly for identifying the nationality and/or institutional type of the investor. However, we focus the analysis on the most important countries, which have a long experience in compiling balance of payments data and international investment positions, while at the same time encompassing all important international investment decisions. The exclusion of Middle East countries, China, and monetary authorities is desired, as they have been purchasing securities to control developments in the exchange rate or strategic assets. Both objectives are not related to the mean-variance optimization.

The CPIS database for the year 1997 covers twenty-nine of the largest economies in the world, nine of which belong to the euro area—Austria, Belgium, Finland, France, Ireland, Italy, Netherlands, Portugal, and Spain; the three old EU member states but not members of the euro area—Denmark, Sweden, and the United Kingdom; another ten developed countries—Australia, Bermuda, Canada, Iceland, Israel, Japan, New Zealand, Norway, Singapore, and the United States; four Asian emerging markets—Indonesia, Korea, Malaysia, and Thailand; and three Latin American emerging markets—Argentina, Chile, and Venezuela. Germany did not report data in 1997, but did so in 2001. Since Germany is a key euro-area member and its international portfolio holdings are substantial, we used an annual database on international investment positions from the Bundesbank to derive the geographical allocation of equities and bonds and notes positions abroad held by German residents at end-1997. Specifically, we use the Bundesbank 1997 and 2001 records and adjust all the 1997 positions consistently (including exchange rate movements) to make them comparable to the 2001 holdings recorded in the CPIS. In all, we employ a matrix formed by thirty countries (that is 870 observations). However, we excluded from the database the investing countries that allocated explicitly to specific receiving countries less than 75 percent of their international portfolio either in 1997 or in 2001, or those countries that held less than 100 million in U.S. dollars in their international portfolio in 1997 or in 2001. In other words, we opted for excluding from the cross-section analysis economies that reported undetermined investment positions vis-à-vis the countries in the sample.[8]

The change in foreign holdings from end-1997 to end-2001 could be due to capital gains, exchange rate changes, portfolio transactions, and other adjustments (i.e., reclassification). Under the hypothesis that cross-border other adjustments are relatively negligible, the actual portfolio flows from the investing country c to the receiving country k over the period 1998–2001, $T_{ck,t}$, can be computed using the IMF data model widely employed in the field of

[8]We excluded the investment of Argentina, Indonesia, Israel, Thailand, and Venezuela from the equity holdings database and the investment of Iceland, Israel, and New Zealand from the long-term debt instrument holdings database. However, in doing so, we simply lose, respectively, 0.05 percent and 0.20 percent of allocated global equity and bond holdings.

balance of payments, international investment positions, and external debt statistics:[9]

$$T_{ck,t} = \left(\frac{Inv_{c,k,01}}{e_{k,01} p_{k,01}} - \frac{Inv_{c,k,97}}{e_{k,97} p_{k,97}} \right) \overline{e}_{k,t} \overline{p}_{k,t}$$
$$= \left[\frac{Inv_{c,k,01}}{(1 + x_{k,t})(1 + r_{k,t})} - Inv_{c,k,97} \right] \frac{\overline{e}_{k,t} \overline{p}_{k,t}}{e_{k,97} p_{k,97}},$$

where $Inv_{c,k}$ is the amount invested by country c in country k financial assets and held in country c currency; e_k and p_k are, respectively, the exchange rate (i.e., country c currency per unit of country k currency) and the asset price in country k financial assets at the end of 1997 and at the end of 2001; $x_{k,t}$ and $r_{k,t}$ are, respectively, the change in the exchange rate and the total asset return over the four-year period; and $\overline{e}_{k,t}$ and $\overline{p}_{k,t}$ are, respectively, the average exchange rate and the average asset price over the same period. This approach implies that transactions are assumed to occur uniformly over the period 1998–2001. However, it facilitates the computation of the bilateral cross-border portfolio flows, as they do not depend on the choice of the price indices' base year.

As for the exchange rate adjustments, one should note that most of the global portfolio allocation is in U.S. dollars and euros. According to a subtotal of thirteen countries used in this study, 75 percent of equity portfolio and 80 percent of long-term debt portfolio are held in these two currencies. International investors also held less than 10 percent of their portfolios in British pounds and Japanese yen. Therefore, it would be a mistake to use local currencies in estimating cross-border portfolio flows. Moreover, London is a key European financial center generally issuing European assets in euros. Since the Japanese yen depreciated by only 1 percent against the U.S. dollar over the 1998–2001 period, and given the lack of a disaggregated currency and geographical breakdown of portfolio holdings, a potential alternative is to assume that all assets issued by European countries are issued in euros, while all assets issued by non-European countries are issued in U.S. dollars. This assumption finds its support in the European Central Bank's studies on the international role of the euro, which point out that (i) the use of the euro in international

[9]See Committeri (2000) for a comprehensive analysis.

markets has a strong regional dimension, as it is focused on countries and financial centers geographically close to the euro area, and (ii) the city of London plays a pivotal role regarding the use of the euro outside the euro area (European Central Bank 2003).

Table 4 reports the estimated cross-border portfolio flows aggregated for the thirty countries in the sample and the aggregate cumulated figures reported by the International Financial Statistics (IFS) of the IMF over the same period. The estimated flows and the IFS figures are not directly comparable, as important countries such as offshore centers and several Asian and Latin American countries are not included in the CPIS database. Moreover, the cross-border flows of debt instruments reported by the IFS include official flows from monetary authorities and are the sum of bond and money market instrument flows. For example, the estimated foreign capital flows in U.S. long-term debt securities amount to USD 173 billion, while the U.S. debt liabilities reported by the IFS, which include the flows of foreign monetary authorities and offshore centers, amount to USD 869 billion. However, it is useful to point out that the reserve assets of Japan, China, and Southeast Asian countries increased by approximately USD 450 billion over the 1998–2001 period, and it is generally agreed that the Asian monetary authorities purchased mostly U.S. Treasury securities. It is also generally believed that monetary authorities might have a different profit-maximizing behavior than private investors. Hence, the exclusion of their investment decisions, which is implicit when using the CPIS database, is cardinal to test the IntCAPM.

Although differences for individual transactions clearly exist, the cross-section is acceptable. In fact, the correlation coefficients between the estimated and the IFS figures amount to 95 percent and 88 percent on the asset side of equity and bond securities, and to 90 percent and 78 percent on their respective liability side.

The aggregate results for four country groupings show that portfolio flows of euro-area member states were substantially larger compared with other regions, particularly in the bond market (see table 5). A deeper inspection of the data reveals, first, that all regions of the world purchased euro-area assets over the period 1998–2001 (see figure 1). Second, intra-euro-area allocation was extremely high. The portfolio transactions among euro-area member states amounted to USD 315 billion in equity securities and USD 754

Table 4. Estimated and IFS Portfolio Flows by Country, 1998–2001 (USD Millions)

	Estimated Using CPIS (Thirty Countries)				IFS (All Countries)			
	Equity		Bonds		Equity		Debt Instruments	
Countries	**Asset (1a)**	**Liability (2a)**	**Asset (3a)**	**Liability (4a)**	**Asset (1b)**	**Liability (2b)**	**Asset (3b)**	**Liability (4b)**
Argentina	7218	−11550	−156	−35509	3057	−14178	1894	9046
Australia	26894	−4497	4210	−5550	21335	28269	13919	34153
Austria	16946	−1668	29931	47256	25912	2034	52613	89330
Belgium	32027	11444	67878	43694	NA	NA	NA	NA
Bermuda	−28958	57574	2077	249	NA	NA	NA	NA
Canada	66765	−11080	−2879	−23388	87687	46318	10347	7349
Chile	1739	−2394	1403	33	7266	460	2460	4358
Denmark	23105	−605	12126	−2865	24464	3184	23611	20122
Finland	16423	46761	26493	−3564	19943	32284	30176	8233
France	96886	95292	204504	159606	96931	130205	318101	286335
Germany	168440	87823	166482	196319	312046	134411	317931	373599
Iceland	1202	124	61	1197	1340	69	142	2836
Indonesia	2	1528	456	−4435	NA	−5732	0	−92
Ireland	87894	44127	107199	26771	116637	248967	227336	40136
Israel	1119	3397	2999	1448	1430	6966	3586	−94
Italy	103132	17	121421	217951	176871	7215	178246	295727
Japan	30703	108697	89918	−7570	77403	157815	362394	133065
South Korea	111	22260	−2066	−34398	1201	39288	5558	−5681
Malaysia	−401	−7773	−9	−6245	NA	NA	0	283

(continued)

Table 4. (Continued)

Countries	Estimated Using CPIS (Thirty Countries)				IFS (All Countries)			
	Equity		Bonds		Equity		Debt Instruments	
	Asset (1a)	Liability (2a)	Asset (3a)	Liability (4a)	Asset (1b)	Liability (2b)	Asset (3b)	Liability (4b)
Netherlands	80771	80545	112355	183460	125570	64234	164841	195377
New Zealand	2071	−3323	1944	−1362	3482	−332	1187	1534
Norway	31222	2658	29083	9315	34820	3296	36574	20665
Portugal	3041	3744	11857	24835	5088	5642	20095	22219
Singapore	9342	15916	30799	8844	34461	2739	12749	801
Spain	40517	29490	65833	79518	63973	46972	132118	100706
Sweden	43503	−12463	19732	−7562	59076	11439	31101	11821
Thailand	−79	3033	208	−6708	NA	2486	505	−3329
United Kingdom	−10753	344075	59398	73361	120922	391493	188547	152808
United States	284130	233116	−68280	173220	431506	469311	39486	868766
Venezuela	1	−1250	−930	−13873	17	61	−178	632
Total	1135015	1135015	1094048	1094048	1861258	1814914	2175337	2670705
Corr. Coefficient	(1): 0.95	(2): 0.91	(3): 0.88	(4): 0.78				

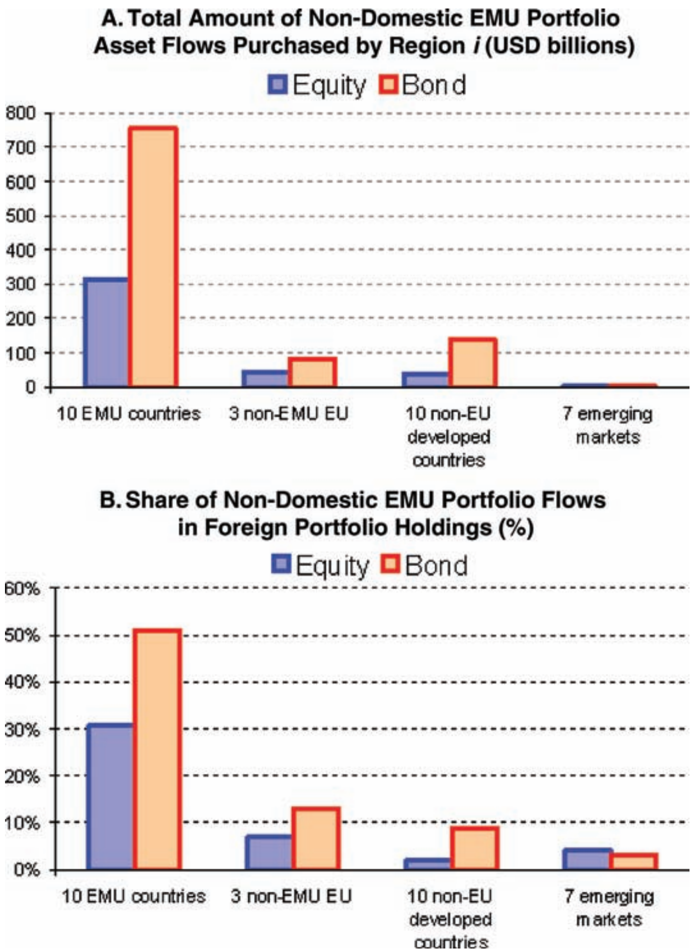
Notes: The first four columns of the table report the results of the estimated net asset transactions over the cumulated period 1998–2001 aggregated for the thirty countries of the sample. The last four columns report the countries' equity and debt flows over the same period reported by the IFS database of the IMF. The estimated and the IFS figures are not directly comparable, as offshore centers, several Asian and Latin American countries, and the official flows of monetary authorities are not included in the CPIS database. Moreover, the debt instrument flows reported by the IFS are the sum of bonds and money market instrument flows.

Table 5. Estimated and IFS Portfolio Flows by Regions, 1998–2001 (USD Billions)

	Estimated from CPIS (Thirty Countries)				IFS (All Countries)			
	Equity		Bonds		Equity		Debt Instruments	
Countries	**Asset (1a)**	**Liability (2a)**	**Asset (3a)**	**Liability (4a)**	**Asset (1b)**	**Liability (2b)**	**Asset (3b)**	**Liability (4b)**
Ten EMU	646.1	397.6	914.0	975.8	943.0	672.0	1441.5	1411.7
Three Non-EMU EU	55.9	331.0	91.3	62.9	204.5	406.1	243.3	184.8
Ten Non-EU Developed	424.5	402.6	89.9	156.4	693.5	714.5	480.4	1069.1
Seven Emerging Markets	8.6	3.9	−1.1	−100.1	11.5	22.4	10.2	5.2
Total	1135.0	1135.0	1094.0	1094.0	1861.3	1814.9	1805.1	2337.6
Corr. Coefficient	(1): 0.99	(2): 0.96	(3): 0.97	(4): 0.84				

Notes: The figures report the portfolio flows of equity and fixed-income aggregated for four country groupings. The ten EMU countries are Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, and Spain. The three non-EMU EU countries are Denmark, Sweden, and the United Kingdom. The ten non-EU developed countries include Australia, Bermuda, Canada, Iceland, Israel, Japan, New Zealand, Norway, the United States, and Singapore. The seven emerging markets are Argentina, Chile, Indonesia, Korea, Malaysia, Thailand, and Venezuela. The first four columns of the table report the results of the estimated net asset transactions over the cumulated period 1998–2001 aggregated for the thirty countries of the sample. The last four columns report the countries' equity and debt flows over the same period reported by the IFS database of the IMF. The estimated and the IFS figures are not directly comparable, as offshore centers, several Asian and Latin American countries, and the official flows of monetary authorities are not included in the CPIS database. Moreover, the debt instrument flows reported by the IFS are the sum of bond and money market instrument flows.

Figure 1. Changes in Non-Domestic Euro-Area Assets by Region



Notes: Panel A reports the estimated portfolio net flows of EMU assets transacted by residents of region i over the period 1998–2001 aggregated for four country groupings. Panel B reports the estimated flows relative to foreign assets held in region i over the average period 1998–2001. The ten EMU countries are Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, Portugal, and Spain. The three non-EMU EU countries are Denmark, Sweden, and the United Kingdom. The ten non-EU developed countries include Australia, Bermuda, Canada, Iceland, Israel, Japan, New Zealand, Norway, Singapore, and the United States. The seven emerging markets are Argentina, Chile, Indonesia, Korea, Malaysia, Thailand, and Venezuela.

billion in bonds and notes (see figure 1A), which represent, respectively, 31 percent and 51 percent of the non-domestic equity and bond assets held on average by euro-area member states over the period 1998–2001 (see figure 1B).

Several transactions are not reported in the CPIS database. This implies either a rational portfolio allocation decision of not investing or the desire of not reporting confidential transactions. Specifically, the zeros reported by countries with more than 75 percent of their international portfolio allocated account for 6.7 percent and 16.6 percent in equity and bond portfolios, respectively. It is important to stress that the zero flows can still occur if there were no transactions or if transactions just offset each other during the 1997–2001 period. Also, negative transactions can occur if countries disinvested in 2001 relative to 1997. Such zero and negative flows are not truncated; they remain part of the database. However, given the zero reporting for some holding positions, we estimate the same model, excluding and including such transactions. As shown in various regressions, results are barely affected, partly suggesting that most of the zero holdings are based on actual portfolio investment decisions.

4. The Empirical Approach: Testing the IntCAPM

In a fully integrated world where purchasing power parity (PPP) holds, Solnik (1974) and Sercu (1980) show that the international version of the simple CAPM of Sharpe (1964) and Lintner (1965) holds. Moreover, the equilibrium is achieved when all investors hold the world market portfolio, where each country's portfolio is weighted by its market capitalization. In this model, the optimal share invested in each country k is equal to that country k's market capitalization weight in the world index portfolio, $w_{k,97}^{Bench}$.

The IntCAPM predicts a coefficient on $w_{k,97}^{Bench}$ equal to unity. However, due to home bias, marginal and fixed transaction costs, asymmetric information, heterogeneous belief about market performance, and trend-chasing behavior, the prediction of the IntCAPM might not hold. Therefore, first we regress bilateral portfolio flows in equity and bond securities upon their respective benchmarks, $w_{k,97}^{Bench}$. Next, we control for the degree of home bias, the non-linear degree of misallocation at the beginning of the period, and asset performance in the previous period. Specifically, we estimate the following model:

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{k,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \varepsilon_t,$$

where $t_{ck,t}$ denotes country c's international transactions invested in country k divided by country c's average international holdings over the 1998–2001 period; $HB_{c,97}$ and $\Delta HB_{c,01}$ are country c's degree of home bias at the beginning of the period and its first difference over the sample period; $DW_{ck,97}$ denotes the degree of underweight of country k assets in investor c's portfolio at the beginning of the period; $r_{k,t-1}$ is the total returns on country k's market portfolio in the previous period; and ε_t is a well-behaved term for all other determinants of portfolio asset flows.

Home bias on the part of an investor, $HB_{c,t}$, is broadly defined as the tendency to invest more in domestic assets even though the risk is shared more effectively if foreign assets are held. We expect that the higher the degree of home bias, the larger the benefits of further cross-border investments and the stronger the incentives for international diversification. Hence, net portfolio flows should be positively related to the degree of home bias at the beginning of the period ($\alpha_2 > 0$) and negatively related to its increase over the period ($\alpha_3 < 0$). An index that is generally used to measure home bias is 1 minus the Foreign Asset Acceptance Ratio (FAAR).[10] FAAR measures the extent to which the share of foreign assets in an investor's portfolio diverges from the share of foreign assets that would be held in a "borderless" global portfolio. By this metric, home bias is higher the lower FAAR is from unity. Specifically, FAAR is computed as the actual share of foreign assets in total country holdings, $w^f_{c,t}$, divided by the optimal share of foreign assets in the total country portfolio, $1 - w^{Bench}_{c,t}$. This implies that

$$HB_{c,t} = 1 - \frac{w^f_{c,t}}{1 - w^{Bench}_{c,t}}.$$

Since this measure is investor specific, it also plays the role of country c's fixed effect.

[10]See, for example, International Monetary Fund (2005) and De Santis and Gérard (2009).

The degree of underweight, DW_{ck}, is defined as the difference between the optimal and actual share of country k assets in investor c's portfolio. It is generally agreed that the higher the costs in a particular foreign market, the more severely underweighted that country will be in the investor's portfolio (Ahearne, Griever, and Warnock 2004). Therefore, we use the initial degree of bilateral misallocation partly to instrument the role played by direct and indirect costs and asymmetric information on bilateral cross-border asset transactions. The larger the initial difference between optimal and actual share, the stronger the incentive to learn about the country and to reduce the associated asset allocation costs in order to trade back to optimal weights, reducing the position when the actual weight exceeds the optimal weight and increasing the investment in an asset when it is underweighted. Since our data focus exclusively on the foreign holdings of each country, the optimal weight to be invested in country k by country c is equal to country k's market capitalization in the world market index, excluding the investing country c. Then

$$DW_{ck,97} = w_{ck,97}^{Bench} - w_{ck,97},$$

where $w_{ck,97}^{Bench} = \frac{w_{k,97}^{Bench}}{1-w_{c,97}^{Bench}}$ and $w_{ck,97} = \frac{Inv_{c,k,97}}{\sum_k Inv_{c,k,97}}$.

Since rebalancing a portfolio entails both direct and indirect fixed transaction costs, it is unlikely to take place when bilateral actual portfolio weights differ only slightly from bilateral optimal portfolio weights. Therefore, we introduce some non-linearities by taking the cube of this measure. We expect that the degree of underweight at the beginning of the period affects non-linearly and positively the geography of portfolio flows ($\alpha_4 > 0$).[11]

[11] Ahearne, Griever, and Warnock (2004) and Portes and Rey (2005) pointed out that direct and indirect costs, such as information costs, to trade assets in a particular foreign market are key reasons why that country is more severely underweighted in the investor's portfolio. While these factors undoubtedly influence firms' decisions about where to invest, a comprehensive evaluation of this motivation is well beyond the scope of this paper, because we do not have measures of bilateral cross-border fixed costs on equity and bond allocation, which often take the form of legal barriers and restrictive regulations. However, once controlling for home bias, the initial non-linear degree of bilateral misallocation could proxy at least partly the initial fixed costs on cross-border portfolio allocation.

If portfolio decisions are based partly on past returns, then investors might tend to underweight countries whose stock markets have performed poorly. Bohn and Tesar (1996) found that international portfolio flows co-move with lagged measures of expected returns. This suggests that international investors engage in positive-feedback trading, also called "trend chasing." To capture this type of "returns-chasing" behavior à la Bohn and Tesar, we use past returns and expect α_5 to be positive.

The results reported in table 6 indicate that $w_{k,97}^{Bench}$ is statistically significant, but its coefficient is less than unity: it is equal to 0.4 for equities and 0.2 for bonds (see specification 1). A country that sees its market size increase by 1 percentage point relative to the world market capitalization would attract international equity (bond) flows amounting to 0.4 percent (0.2 percent) of the equity (bond) assets held abroad by foreigners. The finding that the coefficient on the bond benchmark is half that on the equity benchmark might imply that global equity markets are more integrated than global bond markets.

The results do not change when we control for home bias (see specification 2). On average, the decline in home bias in country c increases international investment toward all destination countries k in both models.

The results also do not change when we control for the non-linear degree of underweight and past performance. Interestingly, the coefficient on $DW_{ck,97}$ is not statistically significant when taking the linear measure (not reported). Conversely, it is strongly statistically significant for the bond flow model when taking the non-linear measure. One potential interpretation is the initial fixed-cost argument discussed above. The willingness to close the initial gap between the share of foreign assets that would be held in a "borderless" global portfolio and actual foreign investment weights is an important determinant of bond flows, as it raises the adjusted R^2 by 7 percentage points, from 14.6 percent in specification 2 to 21.9 percent in specification 3.

Finally, past performance in the destination country is statistically significant for the equity and bond flow models (see specification 4a). While no prudent investor assumes future returns will mirror past returns, trend-chasing behaviors still characterize the geography of international equity and bond flows in the long term.

Table 6. International Portfolio Asset Flows and IntCAPM

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{ck,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \varepsilon_t$$

	Equity Net Asset Flows					Bond Net Asset Flows				
	Specif. 1	**Specif. 2**	**Specif. 3**	**Specif. 4a**	**Specif. 4b**	**Specif. 1**	**Specif. 2**	**Specif. 3**	**Specif. 4a**	**Specif. 4b**
Cst	0.005***	−0.036	−0.036*	−0.039**	−0.038**	0.012***	−0.011**	−0.011**	−0.023***	−0.017***
	(0.002)	(0.019)	(0.002)	(0.019)	(0.019)	(0.002)	(0.006)	(0.006)	(0.006)	(0.005)
$w^{Bench}_{k,97}$	0.427***	0.425***	0.449***	0.441***	0.447***	0.190***	0.193***	0.233***	0.232***	0.234***
	(0.095)	(0.092)	(0.128)	(0.127)	(0.127)	(0.067)	(0.067)	(0.061)	(0.061)	(0.061)
$HB_{c,97}$		0.038	0.038	0.038	0.037		0.015**	0.016**	0.017**	0.012*
		(0.024)	(0.024)	(0.024)	(0.023)		(0.008)	(0.008)	(0.008)	(0.008)
$\Delta HB_{c,01}$		−0.111***	−0.111***	−0.112***	−0.105***		−0.074***	−0.068***	−0.069***	−0.059***
		(0.027)	(0.027)	(0.027)	(0.026)		(0.013)	(0.012)	(0.013)	(0.013)
$DW^3_{ck,97}$			−0.460	−0.491	−0.509			1.384***	1.386***	1.391***
			(1.149)	(1.147)	(1.146)			(0.285)	(0.282)	(0.284)
$r_{k,t-1}$				0.006***	0.005***				0.039***	0.030***
				(0.002)	(0.002)				(0.007)	(0.006)
Adjusted R^2	0.283	0.315	0.315	0.317	0.319	0.104	0.146	0.219	0.235	0.237
$F - Stat$	263.55	102.92	77.63	63.06	68.92	74.85	37.37	45.65	40.15	49.53

Notes: This table reports the results of the cross-sectional regression of the equity and bond net asset flows. The explanatory variables are described in appendix 1. The sample size for specifications 1–4a is $n = 667$ for equity flows and $n = 639$ for bond flows and excludes all zero holdings. The sample size for specification 4b is $n = 725$ for equity flows and $n = 783$ for bond flows and includes all zero holdings. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

All in all, the proportion of the total variation explained by the model is quite significant: 31.7 percent in equity flows and 23.5 percent in bond flows.

The results are barely affected when treating the zero reporting for some holding positions in the sample as actual portfolio investment decisions (see specification 4b).

5. Portfolio Flows, Monetary Policy Frameworks, and EMU

The second aim of the paper is to assess whether central banks' monetary policy frameworks across countries influenced the geography and size of international capital flows during the boom and bust of asset prices at the turn of the century. In this context we also investigate the role of EMU on global portfolio reallocation.

5.1 The Impact of Monetary Policy Frameworks

We use the IntCAPM as our benchmark and add explanatory variables describing key characteristics of monetary policy frameworks across countries. Therefore, we estimate the following model:

$$t_{ck,t} = \alpha_0 + \alpha_1 w_{k,97}^{Bench} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW_{ck,97}^{3} + \alpha_5 r_{k,t-1} + \lambda' \boldsymbol{Mon}_{k,t-1} + \varepsilon_t,$$

where the vector $\boldsymbol{Mon}_{k,t-1}$ includes variables measuring the following characteristics of the monetary policy framework in country k: (i) the central bank's objectives, such as the focus on inflation, on money, on the exchange rate, and on discretionary policy, (ii) the central bank's institutional factors, such as independence, accountability, and transparency, and (iii) the importance of financial stability in the setting of monetary policy instruments. Results reported in table 7 are based on the sample that excludes the zero entry positions. The results are the same when zero holding positions are included in the analysis (not reported; see also table 8).

Among the characteristics related to monetary policy, the focus on money played a significant and positive role in influencing the geography of the portfolio flows. Given the link between asset prices and credit growth (Borio and Lowe 2004; Detken and Smets 2004),

Table 7. International Portfolio Flows and Characteristics of Monetary Policy Frameworks

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{k,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \lambda' \boldsymbol{Mon}_{k,t-1} + \varepsilon_t$$

Specif. Number	Explanatory Variable	Equity Flows			Bond Flows		
		Coeff.	s.e.	$\overline{R}^2$	Coeff.	s.e.	$\overline{R}^2$
Policy Focus							
5	$Inflation_{k,98}$	0.004	(0.006)	0.317	−0.011**	(0.004)	0.237
6	$Money_{k,98}$	0.021***	(0.007)	0.322	0.062***	(0.012)	0.286
7	$Exchange\ rate_{k,98}$	−0.006	(0.006)	0.309	0.005	(0.005)	0.234
8	$Discretion_{k,98}$	0.003	(0.007)	0.317	0.010	(0.008)	0.236
Institutional Factors							
9	$Independence_{k,98}$	0.003	(0.014)	0.317	0.046***	(0.016)	0.240
10	$Accountability_{k,98}$	0.006	(0.008)	0.317	−0.025***	(0.009)	0.245
11	$Transparency_{k,98}$	0.006	(0.008)	0.317	−0.007	(0.006)	0.234
Structural Factors k							
12	$Financial\ Stability_{k,98}$	0.014	(0.009)	0.318	−0.006	(0.008)	0.233
Policy Focus with Germany Being the Benchmark for Other Euro-Area Countries							
5a	$Inflation_{k,98}$	0.003	(0.007)	0.317	−0.014***	(0.004)	0.239
6a	$Money_{k,98}$	0.009**	(0.004)	0.319	0.030***	(0.004)	0.275
7a	$Exchange\ rate_{k,98}$	−0.011***	(0.004)	0.319	−0.018***	(0.004)	0.240
8a	$Discretion_{k,98}$	−0.004	(0.014)	0.313	−0.016**	(0.007)	0.236

(continued)

Table 7. (Continued)

Specif. Number	Explanatory Variable	Equity Flows			Bond Flows		
		Coeff.	s.e.	$\overline{R}^2$	Coeff.	s.e.	$\overline{R}^2$
Institutional Factors with Germany Being the Benchmark for Other Euro-Area Countries							
9a	$Independence_{k,98}$	0.003	(0.012)	0.317	0.063***	(0.014)	0.247
10a	$Accountability_{k,98}$	−0.000	(0.006)	0.317	−0.029***	(0.005)	0.261
11a	$Transparency_{k,98}$	0.012	(0.009)	0.318	−0.006	(0.007)	0.234
Structural Factors with Germany Being the Benchmark for Other Euro-Area Countries							
12a	$Financial\ Stability_{k,98}$	0.010	(0.009)	0.317	−0.006	(0.007)	0.234

Notes: This table reports the results of the cross-sectional regression of portfolio net asset flows. Each explanatory variable of this table is added as an additional regressor to the IntCAPM reported in specification 4 of table 6. As for the characteristics of the monetary policy framework, the indices range between 0 and 1, and a higher score is associated with the higher degree of importance given to policy objectives, to institutional characteristics, and to financial stability issues. The explanatory variables are described in appendix 1. The sample size is $n = 667$ for equity flows and $n = 639$ for bond flows and excludes all zero holdings. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

Table 8. International Portfolio Flows, IntCAPM, and Monetary Policy Frameworks

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{ck,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \lambda Mon_{k,t-1} + \varepsilon_t$$

	Equity Asset Flows						Bond Asset Flows					
	Specif. 13		Specif. 14a		Specif. 14b		Specif. 13		Specif. 14a		Specif. 14b	
Cst	−0.043**	(0.019)	−0.043**	(0.019)	−0.042**	(0.019)	−0.028***	(0.008)	−0.027***	(0.008)	−0.020**	(0.007)
$w^{Bench}_{k,97}$	0.433***	(0.127)	0.436***	(0.128)	0.443***	(0.127)	0.237***	(0.060)	0.214***	(0.062)	0.213***	(0.062)
$HB_{c,97}$	0.037	(0.024)	0.037	(0.024)	0.036	(0.023)	0.016**	(0.008)	0.015*	(0.008)	0.012*	(0.007)
$\Delta HB_{c,01}$	−0.112***	(0.027)	−0.112***	(0.027)	−0.105***	(0.026)	−0.071***	(0.011)	−0.072***	(0.011)	−0.060***	(0.008)
$DW^3_{ck,97}$	−0.516	(1.143)	−0.519	(1.145)	−0.536	(1.143)	1.363***	(0.287)	1.366***	(0.275)	1.377***	(0.275)
$r_{k,t-1}$	0.008***	(0.002)	0.008**	(0.003)	0.006***	(0.002)	0.033***	(0.007)	0.064***	(0.012)	0.054***	(0.010)
$Money_{k,t98}$	0.021***	(0.007)	0.021***	(0.007)	0.021***	(0.006)	0.026**	(0.005)	0.059***	(0.012)	0.054***	(0.011)
$Inflation_{k,98}$	—	—	—	—	—	—	0.007*	(0.004)	0.003	(0.004)	−0.000	(0.003)
$Accountability_{k,98}$	—	—	—	—	—	—	−0.012**	(0.005)	−0.023***	(0.007)	−0.018***	(0.006)
d$Money_{k,98}$			0.002	(0.005)	0.004	(0.004)			−0.008	(0.017)	−0.007	(0.015)
d$Inflation_{k,98}$									0.033**	(0.016)	0.023	(0.014)
d$Accountability_{k,98}$									−0.039	(0.024)	−0.032	(0.022)
$Adjusted\ R^2$	0.322		0.321		0.323		0.276		0.301		0.300	
$F-Stat$	53.70		45.99		50.34		31.37		25.94		30.88	

Notes: This table reports the results of the cross-sectional regression of portfolio net asset flows, summarizing findings in tables 6 and 7. This table also reports the results when controlling for the potential change in the characteristics of the monetary policy frameworks, as a consequence of the establishment of EMU, using the German characteristics as a target benchmark for other euro-area countries. Other explanatory variables are described in appendix 1. The sample size for specifications 13–14a is $n = 667$ for equity flows and $n = 639$ for bond flows and excludes all zero holdings. The sample size for specification 14b is $n = 725$ for equity flows and $n = 783$ for bond flows and includes all zero holdings. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

global portfolio investors might have purchased assets of countries where monetary analysis played a more prominent role.

If the focus on monetary aggregates, credit growth, and financial flows helps central banks identify inflated asset prices and financial imbalances, then portfolio investors would indeed give importance to this characteristic. The empirical results on both equity and bond flows support this hypothesis. In particular, the $\overline{R}^2$ of the model explaining the geography of bond flows increases from 23.5 percent in the benchmark model (see specification 4a of table 6) to 28.6 percent when adding the focus on money by the recipient country's central bank (see specification 6 of table 7).

Among the characteristics related to the institutional factors, independence (specifications 9 and 9a of table 7) is found to be significant and with the expected sign only for bond flows, while being accountable is a push factor of bond flows (specifications 10 and 10a). As already pointed out, independence and accountability are negatively correlated, which implies that explaining and defending monetary policies to government and parliament and the involvement of parliament in monetary policy decisions might be seen by international investors as an infringement on central banks' independence, putting at risk the price stability mandate, which is now a typical mandate by monetary authorities across the globe.

Qualitatively similar results are obtained if we assume that the characteristics of the monetary policy frameworks of the euro-area member states converged with those of Germany with the establishment of EMU (see specifications 5a–12a of table 7). Under this hypothesis, the focus on the exchange rate becomes strongly negatively significant in both equity and bond flow specifications (see specification 7a). This might imply that global asset allocators over the period 1998–2001 reduced their investment vis-à-vis countries whose monetary authorities gave relative importance to exchange rate targets.

When pooling the indices, which are statistically significant in the same model, independence is no longer significant in the bond flow specification, while the focus on inflation has the positive sign (see specification 13 of table 8). Given the establishment of EMU in January 1999, we also control for the potential change in the characteristics of the monetary policy frameworks of the euro-area member states using the German monetary framework as the benchmark. Results, which are reported in specifications 14a and 14b of table 8, indicate that the focus on money and accountability continue to be robust. These will be the only variables that are consistently significant when we study and control for the effect of EMU.[12]

The fact that the focus on inflation or independence has not systematically influenced international capital flows may be simply due to the fact that the core objective of most of the central banks of the countries in the sample is to enforce price stability, with independence being key to control inflationary expectations. Most likely, foreign investors care about inflation only at relatively high levels.

5.2 The Impact of EMU

To control for the effect of EMU on global capital flows as well as to measure its average impact, we include two sets of binary variables. However, the binary variables per se are not sufficient to study the catalyst effect of EMU, because portfolio capital could have been reallocated globally to better exploit the expected diversification benefits and the elimination of the exchange rate risk among euro-area member states.

In 1998, the Maastricht process was well under way and investors were keenly aware of the high likelihood that the intra-EMU currency risk would disappear. Therefore, the expected volatility of the exchange rate is assumed to be zero among euro-area countries and equal to past volatility for the other cross-border transactions. More specifically, the expected volatility of the exchange rate among euro-area member states and other countries of the world is assumed to equal the past volatility of the rest of the world's currencies vis-à-vis the deutsche mark.

As a measure of the expected diversification benefit, De Santis and Gérard (2009) suggest to employ the marginal impact on portfolio risk of increasing or decreasing the investor's position in a particular asset. Recall that the foreign investment portfolio variance can be computed as

$$\sigma^2_{P_c t} = \boldsymbol{w}'_{c,t} \Sigma_{c,t} \boldsymbol{w}_{c,t}.$$

[12] We have also controlled for the average inflation rate over the ten-year period 1992–2001, and the results do not vary.

$\boldsymbol{w}_{c,t}$ is the vector of weights for the N foreign assets and Σ_c the covariance matrix of returns of the foreign assets, where the subscript c indicates that the covariance and weight are computed from the investing country c's perspective. Then, the decrease in portfolio variance for a marginal increase in the weight invested in asset k can be interpreted as a measure of the diversification benefit, $\boldsymbol{DB}_{c,t}$:

$$\boldsymbol{DB}_{c,t} = -\frac{\partial}{\partial \boldsymbol{w}_{c,t}} \sigma^2_{P_c t} = -\frac{\partial}{\partial \boldsymbol{w}_{c,t}} \left[\boldsymbol{w}'_{c,t} \Sigma_{c,t} \boldsymbol{w}_{c,t} \right] = -2\Sigma_{c,t} \boldsymbol{w}_{c,t}.$$

That is,

$$DB_{ck,t} = -\frac{\partial}{\partial w_{ck,t}} \left[\boldsymbol{w}'_{c,t} \Sigma_{c,t} \boldsymbol{w}_{c,t} \right] = -2 \sum_{l=1}^{K} w_{cl,t} \sigma_{lk,t},$$

where $DB_{ck,t}$ measures the diversification benefit of adding asset k to investor c's position. Therefore, we should expect it to be positively related to portfolio asset flows.

For an international investor, however, the return on any foreign asset varies not only because of asset-specific risk but also because of unpredictable fluctuations in exchange rates. Since the currency-risk exposure of asset portfolios can be hedged through derivatives transactions, it may be of interest to distinguish between the pure asset component and the currency-risk component of the diversification benefit motive of portfolio reallocation. Therefore, we consider three measures of diversification benefits: (i) an aggregate measure of diversification benefits based on the investor's foreign investments returns denominated in his domestic currency, $DB^{Agg}_{ck} = DB(r^c_k)$; (ii) a measure of diversification benefits based on the investor's foreign investments fully hedged returns, $DB^{FH}_{ck} = DB(r^k_k)$; and (iii) a measure of diversification benefits based on the currency component of the investor's foreign investments, $DB^{Curr}_{ck} = DB(x^c_k)$.

The first two measures of the diversification benefit are easy to compute based on investor's currency denominated asset returns and local currency denominated returns, respectively. Since $r^c_k = r^k_k + x^c_k$, where r^c_k is the continuously compounded (or log) return on country k's portfolio denominated in currency c, and x^c_k is the change in the exchange rate between currency k and currency c, the third measure, the currency component of the investor's diversification benefits, is then computed by taking the difference between the first two:

$$DB_{ck}^{Curr} = DB_{ck}^{Agg} - DB_{ck}^{FH}.$$

In our context currency risk is important also because the introduction of the euro eliminated a substantial component of currency risk for many international investments in our sample. Therefore, we would also like to disentangle the currency-risk effects of the adoption of the euro from the aggregate currency-risk effects of a change in portfolio allocation. We use the same methodology amply explained in De Santis and Gérard (2009) to construct the measure of diversification benefits based on currency components.

Since rebalancing a portfolio entails transaction costs, it is unlikely to take place when estimated marginal diversification benefits are of small magnitude. Therefore, to introduce some non-linearities, we take the cube of the estimated values of the diversification benefits.

The results point out that the coefficient on the expected volatility of the exchange rate is not statistically significant for equity flows and is only significant at 10 percent for bond flows, with the correct sign in both cases (see specification 15 of tables 9 and 10). As for the diversification benefit, the aggregate marginal diversification benefit is not statistically significant (not reported), while the fully hedged marginal diversification benefit is positive and statistically significant, particularly for bond flows. The results contrast with the findings of Portes and Rey (2005), who found weak support for the diversification motive, possibly because they use bilateral covariances of returns in a common currency as a measure of risk diversification. The impact of the volatility of the exchange rate and of the marginal diversification benefits arising from the currency component are generally small. These findings imply that investors might have preferred to hedge against exchange rate risks over the period 1998–2001.

The econometric results summarized in tables 9 and 10 also suggest that, on top of the mere elimination of the exchange rate risk, EMU played a key role in the allocation of portfolio capital among countries worldwide as well as among euro-area member states, thereby enhancing regional financial integration and risk sharing. The catalyst effect of EMU—which is on top of the mere elimination of the exchange rate risk and due to the reduction of legal barriers, such as the removal of intra-area currency-matching rules, and the

Table 9. International Equity Flows, IntCAPM, Monetary Policy Frameworks, and EMU

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{ck,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \lambda Mon_{k,t-1}$$
$$+\gamma FXvol^e_{ck,t-1} + \beta_1 D_{k\subset EMU} + \beta_2 D_{k\subset EMU}\cdot D_{c\subset EMU} + \beta_3 D_{k\subset UK} + \beta_4 D_{k\subset EMU}\cdot D_{c\subset UK}$$
$$+\beta_5(D_{k\subset EU} - D_{k\subset EMU}) + \beta_6(D_{k\subset EU}\cdot D_{c\subset EU} - D_{k\subset EMU}\cdot D_{c\subset EMU}) + \varphi DB^3_{ck,t-1} + \varepsilon_t$$

	Specif. 15		Specif. 16		Specif. 17a		Specif. 17b	
Cst	−0.046**	(0.019)	−0.046**	(0.020)	−0.046**	(0.019)	−0.046**	(0.020)
$w^{Bench}_{k,97}$	0.422***	(0.116)	0.456***	(0.111)	0.428***	(0.116)	0.425***	(0.132)
$HB_{c,97}$	0.045*	(0.024)	0.045*	(0.024)	0.045*	(0.024)	0.045*	(0.023)
$\Delta HB_{c,01}$	−0.079***	(0.024)	−0.077***	(0.025)	−0.076***	(0.025)	−0.072***	(0.025)
$DW^3_{ck,97}$	−0.348	(1.096)	−0.491	(1.087)	−0.343	(1.098)	−0.311	(1.159)
$r_{k,t-1}$	0.005*	(0.003)	0.001	(0.003)	0.003	(0.003)	0.003	(0.002)
$Money_{k,t-1}$	0.022***	(0.006)	0.018***	(0.006)	0.021***	(0.006)	0.019***	(0.005)
$FXvol^e_{ck,t-1}$	−0.068	(0.247)	−0.087	(0.248)	−0.064	(0.247)	−0.011	(0.076)
$D_{c,EMU}$	−0.007	(0.005)	−0.006	(0.006)	−0.006	(0.005)	−0.006	(0.004)
$D_{EMU,EMU}$	0.033***	(0.006)	0.038***	(0.007)	0.036***	(0.007)	0.035***	(0.005)
$D_{c,UK}$	0.013	(0.032)	—	—	0.009	(0.032)	0.009	(0.034)
$D_{EMU,UK}$	0.083**	(0.040)	—	—	0.076*	(0.039)	0.077*	(0.040)
$D_{c,EU} - D_{c,EMU}$	—	—	0.014	(0.011)	0.004	(0.006)	0.005	(0.006)
$D_{EU,EU} - D_{EMU,EMU}$	—	—	0.018**	(0.009)	0.010	(0.007)	0.010	(0.007)
$DB^{FX^3}_{ck,t-1}$	17.14**	(8.555)	20.17**	(8.278)	17.64**	(8.499)	16.81*	(9.011)
$DB^{EMU^3}_{ck,t-1}$	0.971*	(0.509)	0.588	(0.542)	0.795	(0.519)	0.817	(0.503)
$DB^{X-EMU^3}_{ck,t-1}$	0.063	(0.049)	0.064	(0.049)	0.062	(0.049)	0.045	(0.036)
$Adjusted\ R^2$	0.366		0.352		0.366		0.368	
$F-Stat$	28.48		26.85		25.04		27.37	

Notes: This table reports the results of the cross-sectional regression of portfolio equity net asset flows, summarizing findings in tables 6–8. This table also reports the results when controlling for the potential effect of EMU and of marginal diversification benefits. Explanatory variables are described in appendix 1. The sample size for specifications 15–17a, which excludes all zero holdings, is $n = 667$. The sample size for specification 17b, which includes all zero holdings, is $n = 725$. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

Table 10. International Bond Flows, IntCAPM, Monetary Policy Frameworks, and EMU

$$t_{ck,t} = \alpha_0 + \alpha_1 w^{Bench}_{ck,97} + \alpha_2 HB_{c,97} + \alpha_3 \Delta HB_{c,01} + \alpha_4 DW^3_{ck,97} + \alpha_5 r_{k,t-1} + \lambda Mon_{k,t-1} + \beta_1 D_{k\subset EMU} + \gamma FXvol^e_{ck,t-1} + \beta_1 D_{k\subset EMU} + \beta_2 D_{k\subset EMU}\cdot D_{c\subset EMU} + \beta_3 D_{k\subset UK} + \beta_4 D_{k\subset EMU}\cdot D_{c\subset UK} + \beta_5 (D_{k\subset EU} - D_{k\subset EMU}) + \beta_6 (D_{k\subset EU}\cdot D_{c\subset EU} - D_{k\subset EMU}\cdot D_{c\subset EMU}) + \varphi DB^3_{ck,t-1} + \varepsilon_t$$

	Specif. 15		Specif. 16		Specif. 17a		Specif. 17b	
Cst	−0.019**	(0.007)	−0.020***	(0.007)	−0.019**	(0.007)	−0.016**	(0.006)
$w^{Bench}_{k,97}$	0.212***	(0.058)	0.215***	(0.058)	0.213***	(0.058)	0.218***	(0.060)
$HB_{c,97}$	0.012	(0.007)	0.012	(0.007)	0.012	(0.007)	0.012*	(0.007)
$\Delta HB_{c,01}$	−0.050***	(0.010)	−0.050***	(0.010)	−0.051***	(0.010)	−0.036***	(0.008)
$DW^3_{ck,97}$	1.354***	(0.258)	1.360***	(0.256)	1.354***	(0.259)	1.383***	(0.262)
$r_{k,t-1}$	0.042***	(0.011)	0.040***	(0.012)	0.041***	(0.012)	0.034***	(0.010)
$Money_{k,t-1}$	0.047***	(0.011)	0.046***	(0.011)	0.045***	(0.011)	0.042***	(0.010)
$Accountability_{k,98}$	−0.017**	(0.007)	−0.014**	(0.007)	−0.016**	(0.007)	−0.014**	(0.006)
$FXvol^e_{ck,t-1}$	−0.158*	(0.092)	−0.166*	(0.092)	−0.155*	(0.093)	−0.115*	(0.064)
$D_{c,EMU}$	0.009*	(0.004)	0.010**	(0.005)	0.009**	(0.005)	0.006	(0.004)
$D_{EMU,EMU}$	0.037***	(0.008)	0.038***	(0.008)	0.036***	(0.008)	0.042***	(0.008)
$D_{c,UK}$	0.039***	(0.013)	—	—	0.037***	(0.013)	0.038***	(0.012)
$D_{EMU,UK}$	−0.017	(0.019)	—	—	−0.016	(0.019)	−0.017	(0.018)
$D_{c,EU} - D_{c,EMU}$	—	—	0.015**	(0.006)	0.003	(0.006)	0.002	(0.005)
$D_{EU,EU} - D_{EMU,EMU}$	—	—	−0.003	(0.006)	−0.001	(0.005)	0.002	(0.005)
$DB^{FX^3}_{ck,t-1}$	37283***	(4880)	36135***	(4925)	37244***	(4836.8)	38729***	(4872.7)
$DB^{EMU^3}_{ck,t-1}$	−12.367	(82.86)	−13.813	(82.58)	−11.969	(82.93)	−19.709	(15.83)
$DB^{X-EMU^3}_{ck,t-1}$	−0.150	(0.100)	−0.156	(0.100)	−0.150	(0.100)	−0.031	(0.015)
Adjusted R^2	0.366		0.359		0.364		0.360	
$F - Stat$	25.59		24.85		22.52		26.83	

Notes: This table reports the results of the cross-sectional regression of bond net asset flows, summarizing findings in tables 6–8. This table also reports the results when controlling for the potential effect of EMU and of marginal diversification benefits. Explanatory variables are described in appendix 1. The sample size for specifications 15–17a, which excludes all zero holdings, is $n = 639$. The sample size for specification 17b, which includes all zero holdings, is $n = 783$. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

sharing of common platforms, such as Euronext—is the estimated coefficient on $D_{EMU,EMU}$. It is positive and strongly statistically significant for both equity and bond flows.

Unfortunately, the lack of back data on bilateral portfolio flows does not allow us to verify whether the upward trend in intra-euro-area portfolio flows from 1998 onward already started before the establishment of EMU. Indeed, we could have captured the process of financial integration in the EU, as a result of EU policies aiming at liberalizing cross-border portfolio allocation among EU member states in the 1990s. However, we can run a similar exercise including binary variables aiming at controlling for the EU effect. Given the strong correlation between the dummies capturing both the EU and the EMU effects, we subtract the EMU dummies from the EU dummies. The estimated coefficient on $D_{EMU,EMU}$ remains strongly statistically significant in both equity and bond markets (see specification 16 of tables 9 and 10). Moreover, the results reported in specifications 16 and 17a of tables 9 and 10 indicate that the European dummies are not statistically significant once we control for London as a major intermediary of euro-area foreign investments from and to the rest of the world.

Needless to say, the results remain invariant when we include the zero holding positions in the sample and treat them as actual portfolio investment decisions (see specification 17b of tables 9 and 10).

Therefore, there is evidence of a positive EMU effect on cross-border portfolio flows. On a 95 percent confidence level, the catalyst effect of the euro within the euro area over the cumulated period 1998–2001 amounted to USD 22–47 billion in equity securities and USD 32–76 billion in bonds and notes. On average, the impact on the fixed-income market is larger possibly because European institutional investors invested massively in domestic government debt. The adoption of the euro currency-matching rule allowed them to rebalance into euro-denominated bonds issued by other EMU member states.

All in all, the link between international portfolio flows, the Int-CAPM, characteristics of monetary policy frameworks, and EMU is quite robust also in terms of adjusted R^2, which is above 35 percent in both models. This result is very important given that the analysis has been carried out in the middle of an equity bubble and burst, during therefore an extremely difficult period for global asset management.

6. Adding Control Variables

The literature on portfolio flows has put forward a number of variables potentially affecting the cross-border investment allocation. The aim of this section is to assess how robust the results are when adding control variables to specification 15 of tables 9 and 10. The results reported in table 11 are obtained using the sample, excluding the zero reporting for some holding positions. The results are invariant when considering such zeros in the sample (not reported).

The “stages of development hypothesis” postulates an inverse U-shaped relationship between capital inflows and relative per capita income. Countries in the early stages of development tend to experience capital inflows, which arise from building the infrastructure and expanding domestic markets. In a subsequent phase, as new ideas are transformed into products and services and the country develops some comparative advantages in specific industries, its per capita income rises and capital inflows decline. However, it is often argued that portfolio flows are particularly sizable among developed countries, against the prediction of the “stages of development hypothesis” (Lucas 1990). Indeed, country k's GDP per capita polynomial is not statistically significant for the equity market and is even positive for the bond market (see specification 18 of table 11).

Investment in research and development (R&D) is generally considered a good policy to enhance the productivity of a country. If capital has a higher return in countries investing in R&D, the allocation of portfolios should also be partly affected. The imperfection in international credit markets can affect the amount and the direction of portfolio flows (Portes and Rey 2005).[13] A structural determinant of national savings is the demographic profile of a country. Relatively high youth and old-age dependency ratios would bring about net capital inflows, as a relatively large population of dependent young and old has a relatively lower savings rate (Ando

[13]R&D and bank credit to the private sectors are strongly correlated with the GDP per capita (see table 3), because richer countries generally have more resources to finance the private sector and the expenditure in R&D.

Table 11. International Portfolio Flows, Development, Institutions, Distantness, and Net Issuance

Specif. Number	Explanatory Variable	Equity Flows			Bond Flows		
		Coeff.	s.e.	$\overline{R}^2$	Coeff.	s.e.	$\overline{R}^2$
	Degree of Economic Development						
	$pcGDP_{k,97}$	−0.000	(0.001)		0.002***	(0.001)	
18	$pcGDP^2_{k,97}$	0.002	(0.020)	0.364	0.055**	(0.025)	0.367
19	$Bank\ credit/GDP_{k,97}$	0.002	(0.005)	0.365	−0.003	(0.002)	0.366
20	$R\&D/GDP_{k,97}$	0.081	(0.224)	0.365	−0.102	(0.158)	0.366
	$Young_{k,97}$	0.031	(0.021)		0.005	(0.032)	
21	$Old_{k,97}$	0.028	(0.052)	0.365	0.007	(0.060)	0.364
	$\text{soph}_{c,98}$	0.001	(0.002)		0.001	(0.002)	
	$\text{soph}_{k,98}$	0.000	(0.002)		0.005***	(0.002)	
22	$\text{dsoph}_{k,t}$	−0.003	(0.007)	0.364	0.009**	(0.005)	0.367
	Institution Quality						
23	$Liberties_{k,97}$	0.006	(0.007)	0.365	0.008	(0.005)	0.366
24	$La\ Porta_{k,97}$	−0.004	(0.014)	0.365	0.014	(0.019)	0.366
25	$ICRG_{k,97}$	−0.038	(0.035)	0.365	0.008	(0.021)	0.366
26	$Corruption_{k,97}$	−0.003	(0.007)	0.365	0.009	(0.007)	0.366

(continued)

Table 11. (Continued)

Specif. Number	Explanatory Variable	Equity Flows			Bond Flows		
		Coeff.	s.e.	$\overline{R}^2$	Coeff.	s.e.	$\overline{R}^2$
			Distantness				
27	$Distance_{ck,97}$	−0.004	(0.003)	0.367	0.001	(0.002)	0.366
28	$Trade_{ck,97}$	0.043*	(0.026)	0.368	0.002	(0.046)	0.366
29	$Tel_{ck,98}$	−0.007	(0.007)	0.366	0.002	(0.008)	0.366
30	$Language_{ck,97}$	−0.000	(0.009)	0.365	0.015**	(0.007)	0.371
			Economic Growth				
31	$\Delta GDP_{k,t-1}$	0.001	(0.027)	0.365	−0.039**	(0.017)	0.368
			Net New Issuance				
32	$Issues_{k,t}$	0.032*	(0.017)	0.366	0.022***	(0.006)	0.372

Notes: This table reports the results of a cross-sectional regression of portfolio net asset flows. Each explanatory variable of this table is added as an additional regressor to the model specifications 15 of tables 9 and 10. The explanatory variables are described in appendix 1. The sample size is $n = 667$ for equity flows and $n = 639$ for bond flows and excludes all zero holdings. OLS, White heteroskedasticity-consistent standard errors, and covariance. Standard errors for the coefficients are reported in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively.

and Modigliani 1963). All these variables are not statistically significant (see specifications 19–21 of table 11). Let us stress that these results are based upon a cross-section analysis, where most of the countries share similar characteristics.

Portes and Rey (1995) argue that the sophistication of financial markets is an important determinant of equity flows. However, our results do not support this hypothesis. At the same time, the sophistication of financial markets in the recipient country and its development over time are statistically significant for bond flows (see specification 22).

Several studies argue that institutions matter in shaping the net flow of capital across countries (Alfaro, Kalemli-Ozcan, and Volosovych 2007; Coeurdacier, De Santis, and Aviat 2009; De Santis and Lührmann 2009). International investment decisions are affected by risks as well as by the countries' institutional framework, as turmoil, violence, instability, rule of law, property rights, and freedom influence economic market sentiment. We expect that countries with better institutions should attract portfolio flows. To assess the role of the quality of the institutions, we look at standard indices such as the degree of civil liberties; the degree of political, financial, and economic risks; the degree of perceived corruption; and the degree of contract repudiation and expropriation risks.[14] The results are generally weak (see specifications 23–26), possibly because most of the bilateral transactions in this study occur across developed countries, which generally have an adequate institutional setting.

To assess the role of distantness, we consider geographical distance, bilateral trade intensity, phone-traffic volume, and common language. The phone-traffic volume can be interpreted as a proxy for information flows (Portes and Rey 2005), while common language can be interpreted as a proxy for cultural similarities.[15] Trade in

[14] All indices proxying for the quality of the institutions are strongly correlated among them as well as vis-à-vis the GDP per capita, in that richer countries have better institutions (see table 3).

[15] Common language is a dummy that takes the value of 1 if receiving and investing countries share the same language. The language groupings are as follows: English (Australia, Bermuda, Canada, Ireland, New Zealand, Singapore, the United Kingdom, and the United States); Spanish (Argentina, Chile, Spain, and Venezuela); French (Belgium, Canada, and France); German (Austria and Germany); Dutch (Belgium and Netherlands); and Scandinavian (Denmark, Norway, and Sweden).

goods and services could facilitate the information flow across trade partners, increasing the willingness to conduct cross-border portfolio transactions. However, trade costs can also explain the equity portfolio home bias (Obstfeld and Rogoff 2001). In both interpretations, the deeper the trade relationship between countries, the deeper their asset trade flow. There is some mild evidence for the trade variable affecting equity flows (see specification 28) and for common language having an impact on bond flows (see specification 30).

Finally, we also control for economic growth in the destination country. Negative economic growth performance in the destination country over the previous four years affects positively the subsequent bond flows, possibly because a rebound in GDP growth might be expected (see specification 31).

The analysis so far presented focused on changes in demand. However, could important shifts occurring also on the supply side affect the results? The Maastricht Accord imposed tight restrictions on government debt. The effects of this were not symmetric across countries and may have had a significant impact on the composition of fixed-income securities available to investors. To assess whether the results remain robust to changes on the supply side, we use BIS data to compute the net new international equity and bond issues (the difference between completed issues and redemptions in a given period) over the period 1998–2001, which permit us to measure the amount of new funds raised on the international markets. The net issuance of each individual country is then scaled by the total country portfolio. The results indicate that portfolio flows were also affected by the new funds raised on the international markets by the destination country (see specification 32).

All the results on the other regressors presented in tables 9 and 10 remain unaltered when controlling for the effects of all these variables, as implicitly suggested by reporting the adjusted R^2 in table 11.

7. Conclusions

It is generally believed that the predictions of the International Capital Asset Pricing Model (IntCAPM) do not hold because of home bias, transaction costs, asymmetric information, speculative behaviors of investors, etc. We have presented a simple modeling framework showing that the geography of international portfolio flows is only partly influenced by the IntCAPM. Using bilateral data on international equity and bond flows, we find clear evidence that investors do not hold assets of each country in proportion to the country's share in the world market portfolio. However, the predictions of the IntCAPM are partially met because the estimated coefficient, rather than being 1, is 0.4 for equity flows and 0.2 for bond flows. A country that sees its market size increase by 1 percentage point relative to the world market capitalization would attract international equity (bond) flows amounting to 0.4 percent (0.2 percent) of the equity (bond) assets held abroad by foreigners. This might also imply that global equity markets are more integrated than global bond markets and that there is still room for further integration in both markets. The results remain invariant when controlling for home bias, the initial degree of misallocation, and past returns.

Additional findings suggest that (i) a decline in home bias generates portfolio outflows vis-à-vis all countries; (ii) the higher the initial non-linear degree of misallocation, which might be due to higher fixed transaction costs and information asymmetries, the greater the incentive to reduce them and, consequently, the larger the subsequent bond flows; and (iii) asset allocators engage in trend-chasing activities, particularly in bond markets.

We have also investigated whether characteristics of the monetary policy frameworks and the establishment of EMU influenced portfolio asset flows over the turbulent 1998–2001 period for the asset markets. We find clear evidence that investors preferred portfolio assets of countries where the central bank gave relative importance to money. With consumer price inflation well anchored, monetary analysis might have provided a framework for monitoring and assessing developments in asset prices and financial imbalances, cardinal to international investors when forming expectations on future risk-adjusted asset returns. As for EMU, once controlling for diversification benefits and the elimination of the exchange rate risk, we show that cross-border portfolio flows among euro-area countries have increased due to the catalyst effect of EMU (i.e., reduction of legal barriers, sharing of common platforms, and simplification of cross-border regulations). Therefore, we can safely say that EMU has enhanced regional financial integration among euro-area member states in both equity and bond markets.

All in all, countries' shares in the world market portfolio, home bias, initial degree of misallocation across countries, past returns, diversification benefits, monetary policy frameworks, and EMU can explain 35–40 percent of the total variation in equity and bond portfolios over the turbulent 1998–2001 period, characterized by an equity bubble and the subsequent burst.

Appendix 1. Definitions of Variables

Variables	**Definitions**
$t_{ck,t}$	International transactions invested in country k divided by country c's average international holdings
$w_{k,97}^{Bench}$	Country's share in the world market portfolio
$HB_{c,97}$	Home bias of investing country c in 1997
$\Delta HB_{c,97}$	$HB_{c,01} - HB_{c,97}$
$DW_{ck,97}$	Difference between optimal and actual weights in 1997
$Ret_{k,t-1}$	Total market return of receiving country k end-1993 to end-1997
$Inflation_{k,98}$	Inflation focus index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Money_{k,98}$	Money focus index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Exchange\ rate_{k,98}$	Exchange rate focus index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Discretion_{k,98}$	Discretion focus index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Independence_{k,98}$	Independence index in country k in 1998: 0 (lowest importance) and 1 (highest importance)

(continued)

Variables	**Definitions**
$Accountability_{k,98}$	Accountability index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Transparency_{k,98}$	Transparency index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$Financial\ Stability_{k,98}$	Financial stability role index in country k in 1998: 0 (lowest importance) and 1 (highest importance)
$FXvol^{e}_{ck,t-1}$	Standard deviation of the bilateral exchange rate change from 1993 to 1997 with deutsche mark being the EMU currency
$D_{c,EMU}$	Dummy is 1 if receiving country belongs to the euro area
$D_{EMU,EMU}$	Dummy is 1 if receiving and investing countries belong to the euro area
$D_{c,UK}$	Dummy is 1 if receiving country belongs to the United Kingdom
$D_{EMU,UK}$	Dummy is 1 if investing country belongs to EMU and receiving country to the United Kingdom
$D_{c,EU}$	Dummy is 1 if receiving country belongs to the EU
$D_{EU,EU}$	Dummy is 1 if receiving and investing countries belong to the EU
$DB^{FH}_{ck,t-1}$	Expected diversification benefits—fully hedged returns
$DB^{EMU}_{ck,t-1}$	Expected diversification benefits—internal EMU currency exposure
$DB^{X-EMU}_{ck,t-1}$	Expected diversification benefits—external EMU currency exposure
$pcGDP_{k,97}$	Country k GDP per capita minus the GDP per capita of Norway in 1997 (2000 international PPP—$1,000)
$pcGDP^{2}_{k,97}$	The square of country k GDP per capita minus the GDP per capita of Norway in 1997 divided by 1,000

(continued)

Variables	**Definitions**
$Bank\ credit_{k,97}$	Bank credit to the private sector as a ratio to GDP of country k in 1997 minus the world average
$R\&D_{k,97}$	R&D expenditure as a ratio to GDP of country k in 1997 minus the world average
$Young_{k,97}$	Young dependents to working-age population in country k relative to the world average in 1997
$Old_{k,97}$	Old dependents to working-age population in country k relative to the world average in 1997
$\text{soph}_{c,98}$	Sophistication of financial markets in country c in 1998
$\text{soph}_{k,98}$	Sophistication of financial markets in country k in 1998
$\text{dsoph}_{k,t}$	Change in the sophistication of financial markets in country k, 1998 to 2001
$Liberties_{k,97}$	Civil liberties index in country k in 1997: 0 (highest degree of freedom) and 1 (lowest degree of freedom)
$La\ Porta_{k,97}$	La Porta et al. (1998) index in country k in 1997: 0 (highest risk) and 1 (lowest risk)
$ICRG_{k,97}$	International Country Risk Guide rating in country k in 1997: 0 (highest risk) and 1 (lowest risk)
$Corruption_{k,97}$	Perceived corruption index in country k in 1997: 0 (highest risk) and 1 (lowest risk)
$Distance_{ck,97}$	Logarithm of physical distance between capital cities
$Trade_{ck,97}$	Country k's export share in country c plus country c's export share in country k in 1997
$Tel_{ck,97}$	Phone traffic (minutes per 1,000 subscribers) between investing and receiving markets in 1997
$Language_{ck,97}$	Dummy is 1 if receiving and investing countries share the same language
$\Delta GDP_{k,t-1}$	Log-difference of the receiving country's GDP in USD at constant prices from 1993 to 1997
$Issues_{k,t}$	Net new issuance (completed issues minus redemptions) from 1998 to 2001 divided by total country k portfolio in 1997

Appendix 2. Data Sources

Data	Primary Sources	Secondary Sources
International Portfolio Holdings	IMF-CPIS 1997, 2001	Germany: Bundesbank, 1997
Real, Nominal, and Per Capita GDP	Word Bank—WDI	
Equity Market Capitalization	Thomson Datastream/S&P	Bermuda Stock Exchange
Bond Market Capitalization	Lehman Brothers	
Domestic Bonds Outstanding	BIS	
Equity Markets Total Returns	Thomson Datastream	Bermuda Stock Exchange
Bond Markets Total Returns	JP Morgan	
Exchange Rates	Thomson Datastream	
Phone-Traffic Volume	World Bank—WDI	
Age Dependency Ratios	UN World Population Prospects	
Trade Values	IMF	Bermuda and Israel: OECD
Bank Credit to the Private Sector	World Bank—WDI	
R&D Expenditure	World Bank—WDI	
Civil Liberties Index	Freedom House	
La Porta Index	La Porta et al. (1998)	
ICRG Index	International Country Risk Guide	
Corruption Index	Transparency International	
Monetary Policy Frameworks	Mahadeva and Sterne (2000)	
Sophistication of Financial Markets	World Economic Forum	
Net New Issuance	BIS	

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Fixed- and Variable-Rate Tenders in the Management of Liquidity by the Eurosystem: Implications of the Recent Credit Crisis*

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Most liquidity-providing operations of the European Central Bank (ECB) have been conducted through variable-rate tenders. However, fixed rates were first employed in the main refinancing operations (MROs) and are still used in other liquidity management operations. In October 2008, the ECB decided to carry MROs again at a fixed rate. In a simple three-stage game in which banks can obtain liquidity through the open-market operations of the ECB, through interbank transactions, or through "standing facilities," this paper revisits the dilemma between fixed- and variable-rate procedures, with an emphasis on the scenarios that are particularly relevant under the recent credit crisis, namely collateral shortage, rationing in the interbank market, and non-acute estimation by the ECB of the system's liquidity needs.

JEL Codes: D44, E52, G21.

1. Introduction

The primary objective of the monetary policy of the Eurosystem is to maintain price stability. The Governing Council's decisions on the level of the reference interest rates serve this objective, and so do the various instruments and procedures at disposal used to keep money market interest rates in line with the key policy rates. Open-market operations are a crucial instrument of the monetary policy of the European Central Bank (ECB). Among them, main

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refinancing operations (MROs) are the most important in terms of liquidity provision to banks but, during the financial market turmoil that began in the summer of 2007 and intensified in 2008, longer-term refinancing operations (LTROs) have also played an important role to improve the liquidity position of banks and provide broad access to funding. Indeed, supplementary LTROs were carried out with a high frequency, in addition to the Eurosystem's regular tender operations. Also, to alleviate pressures on the market for U.S. dollars (USD), several liquidity-providing operations in USD have been launched, at a fixed rate (equal to the marginal rate of the simultaneous Federal Reserve System tender). In October 13, 2008, the ECB announced that tenders of USD funding would be conducted regularly at least until January 2009, every Wednesday, at a fixed rate with full allotment. The use of fine-tuning operations also intensified during the credit crisis, with an enlargement in the range of institutions that are eligible to participate (October 3, 2008). Most of these fine-tuning operations took place to absorb excess liquidity, at a fixed rate (equal to the minimum bid rate of MROs).

Since the beginning of Stage Three of the Economic and Monetary Union (EMU) in January 1999, and until June 2000, the Eurosystem conducted its MROs through fixed-rate tenders (without full allotment). This procedure, aimed at clearly signaling the stance of monetary policy, involved some distortions in the bidding behavior of banks (overbidding) and led to very small allotment ratios. The change to a variable-rate procedure was introduced in the MRO of June 28, 2000, and was in practice until the operation settled on October 8, 2008. According to the European Central Bank, "The switch to variable rate tenders was a response to the severe overbidding which had developed in the context of the fixed rate tender procedure. . . . In the last two main refinancing operations executed prior to the switch to the variable rate tender, the allotment ratio was below 1%" (European Central Bank 2000, p. 37). The return to the fixed-rate format, however, had never been excluded by the ECB, which retained the option of reverting to it, if and when this is deemed appropriate. The two changes introduced in March 2004 in the operational framework of the Eurosystem—namely, the reduction in the maturity of the MROs and the commitment that rate changes would not occur during the maintenance period—were recognized by the ECB as improving the efficiency of the fixed-rate procedure, because they would prevent the occurrence of excessive overbidding associated with expectations of rising interest rates (European Central Bank 2003). On October 8, 2008, the Governing Council decided to perform the next MROs at a fixed rate, starting with the one settled on October 15 and at least until the end of the first maintenance period of 2009. These operations would take place with full allotment at the interest rate that resulted from the simultaneous ease in monetary conditions (3.75 percent).

LTROs, in turn, have usually been executed in the form of variable-rate tenders, but the possibility of using fixed-rate procedures, "under exceptional circumstances," is not excluded (European Central Bank 2008a, p. 15).

Bearing in mind all these aspects, the present paper revisits the debate between fixed- and variable-rate procedures, with a special focus on the scenarios most relevant under the recent credit crisis, namely (i) rationing in the interbank market—due to high uncertainty as to the solvency of borrowers and as to the evolution of own liquidity requirements; (ii) binding collateral (to address this problem, the ECB expanded the collateral acceptable in lending operations, in its biennial review of September 4, 2008); and (iii) non-acute estimation by the ECB of the true liquidity needs of the system, which are difficult to predict under the prevailing tensions.

Banks can obtain/place liquidity in three markets: (i) the primary market, through the open-market operations of the ECB;[1] (ii) the secondary market or interbank market, where liquidity is traded among banks; and (iii) the "standing facilities"—lending or deposit—of the ECB, at penalty rates. All operations with the ECB must be collateralized, either in the primary or in the tertiary market. In contrast, the exchange of liquidity in the secondary market is assumed to be uncollateralized, which reinforces the risk involved.

During the periods of fixed-rate MROs, the ECB sets the interest rate at which the operations are conducted (the main refinancing rate) and also the marginal lending and deposit interest rates. Only the interbank market rate (a short-term rate) is determined by demand and supply forces. In a variable-rate tender procedure, the prevailing primary market rate fluctuates according to market

[1] For a detailed description of the auction environment, see, for instance, Scalia, Ordine, and Bruno (2005).

conditions in a given interval (the minimum bid rate is established by the Governing Council in its monetary policy meetings), and the ECB uses the amount of liquidity allotted to steer its behavior.[2] The marginal lending and deposit rates are used as policy instruments too, delimiting the "corridor" for interbank rates. In the management of the recent crisis, this "corridor" was shortened from 200 to 100 basis points.

Taking into account the variety of instruments currently in use, this paper compares, in a simple three-stage game, the two tender formats with respect to induced bidding behavior and allocation of liquidity in the primary market, functioning of the secondary market, and resorting to "standing facilities" (tertiary market). The conclusions as to these aspects reinforce previous results in the literature. Specifically, the overbidding phenomenon is indeed shown to be an equilibrium outcome of fixed-rate tenders (without full allotment), a problem which may be avoided by variable-rate tenders. Furthermore, variable-rate tenders allow keeping some informational content of quantity bids, as opposed to fixed-rate tenders. Announcing that there will be full allotment in fixed-rate tenders (October 8, 2008) helps prevent these problems, but in reality there is no auctioning taking place, because the Central Bank has a perfectly elastic supply and fully satisfies the liquidity needs at the prevailing rate.[3] Although simple, the present model further allows us to address the possible implications of some facts deriving from the recent credit crisis, such as collateral shortage, credit rationing in the interbank market, and wrong estimation by the ECB of the true system's liquidity needs. In the 2008 ECB annual report on EU banking structures, and reflecting the prevalent high degree of uncertainty, banks in the European Union have, for the first time, identified financial markets as the major source of risk for the coming year (see European Central Bank 2008b).

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[2]For example, to contain pressures on euro overnight rates, the ECB has accommodated counterparties' wishes to fulfill reserve requirements early in the maintenance period, therefore alloting excess liquidity in the MROs, which is later absorbed at the end of the period.

[3]Prior to this announcement, some MROs of the Eurosystem had already been conducted with full allotment, allocating liquidity in excess of the benchmark amount.

To my knowledge, among other studies addressing the open-market operations of the ECB, the closest to this are Ayuso and Repullo (2003), Bindseil (2002), and Nautz and Oechssler (2003), in the sense that they also compare fixed- and variable-rate procedures. However, apart from Bindseil (2002), who takes care of situations in which the central bank tends to provide surplus liquidity or is systematically tight, none of them addresses the other relevant scenarios for the recent credit crisis: binding collateral and interbank rationing. Ayuso and Repullo (2003) assume that the ECB wants to minimize deviations of the interbank rate from the target rate that signals the stance of monetary policy. They show that when the penalty is higher for rates below the target, pre-announcing the amount of the liquidity injection eliminates overbidding in a variable-rate tender, but the equilibrium in a fixed-rate tender is still characterized by extreme overbidding. Bindseil (2002) compares the two types of tenders, alternatively in the absence and in the presence of interest rate change expectations. He concludes that the fixed-rate tender works well when interest rates are stable (a result that would support the change in the operational framework of the ECB; see European Central Bank 2003), but that the variable-rate tender is better suited in an environment of strong interest rate change expectations. Nautz and Oechssler (2003) conclude for bidding behavior indeterminacy in fixed-rate tenders, and, using a dynamic version of their model, they also conclude that overbidding is an increasing phenomenon in these auctions. The authors also develop an empirical analysis, confirming the weakness of fixed-rate tenders and showing that the move to variable-rate tenders significantly improved liquidity management by the ECB.

There have actually been many empirical studies on the performance of the monetary policy of the ECB. Among them, Ayuso and Repullo (2001) test whether the overbidding problem during the fixed-rate tenders period was due to expectations of a future tightening of monetary policy or to the liquidity allotment decisions of the ECB that resulted in a positive spread between the interbank rate and the interest rate of the MROs. The authors conclude in favor of the latter hypothesis. Scalia, Ordine, and Bruno (2005) address the degree of integration and the bidding efficiency in the primary market during a sample period for variable-rate tenders, using panel information with country effects, bank size effects, and bank group effects. They conclude that bidders in the Eurosystem auctions behave efficiently and that, although the effects mentioned may be significant to some extent, market integration is promoted by liquidity supply through MROs and by the bidding behavior of banks. Nautz and Oechssler (2006) investigate the subsistence of overbidding in fixed-rate tenders if one controls for interest rate expectations (which the ECB proposes in its recent modifications to the operational framework), for the magnitude of the spread between the main refinancing rate and the interbank rate, and for the possibility of banks being squeezed. Their results suggest that none of these three hypotheses is sufficient to eliminate the overbidding problem.

The remainder of the paper is organized as follows. Section 2 presents the notation common to both models (fixed and variable rate). In section 3 the equilibrium bidding behaviors in the fixed-rate auction are derived under several scenarios, namely lack of collateral, credit rationing in the secondary market, and wrong estimation by the ECB of banks' liquidity needs. The corresponding analysis for the variable-rate auction is performed in section 4.[4] Section 5 compares and summarizes results for both types of tender and section 6 concludes.

2. Notation

Consider two representative banks, one which expects not to be a liquidity supplier in the secondary market (i), and one which has the opposite expectation (j). In equilibrium these expectations are confirmed. The equilibrium behaviors of banks i and j replicate the bids of banks that expect to have these positions in the interbank market.

Non-zero banks' liquidity needs are denoted by $\bar{l}_i$ and $\bar{l}_j$. Liquidity obtained in the primary market is l_i and l_j, so bank i still needs $\bar{l}_i - l_i \geq 0$, while bank j has $l_j - \bar{l}_j \geq 0$ in excess.

The interest paid by the central bank's deposit facility is d, and the interest charged on the marginal lending facility is denoted by m. In a fixed-rate tender there is another administered interest rate,

[4] Full details are available in Catalão-Lopes (2001).

denoted by r, with $r \in]d, m[$, and which is the rate paid for the liquidity obtained in the MRO. In a variable-rate tender there may exist a minimum interest rate for bids, also chosen by the ECB. The amount of liquidity that bank i (j) proposes to buy in the MRO is b_i (b_j). In a variable-rate procedure the bank also makes a bid, denoted by r_i (r_j), for the price to pay for this liquidity.

The unsecured interbank rate is denoted by o (overnight rate). Bank j is not willing to sell liquidity at a price below d, so o is bounded from below by d; however, bank i may be willing to buy at an interest rate higher than m, in case collateral is insufficient to satisfy the remaining liquidity needs through the lending facility (remember that, contrary to operations with the ECB, transactions in the interbank market are uncollateralized).

Banks wish to minimize the expenditure they must incur in order to comply with reserve requirements. Both games—fixed- and variable-rate auctions—have three stages: MRO, interbank market, and "standing facilities."[5] The problems are solved backwards.

The optimum bidding behavior in the first market arises from the first-order conditions of the expenditure minimization problem (assuring second-order conditions for a minimum are verified). In a fixed-rate tender there is only one decision variable, the quantity bid, whereas in a variable-rate tender there is an additional one, the interest rate that the bank proposes to pay for the quantity bid it makes. Banks and the monetary authority are assumed to be risk neutral.

3. Fixed-Rate Tenders

In a fixed-rate tender without full allotment, each bank is allocated an amount proportional to its bid (under the implicit assumption that total bids exceed the allotted amount). The allotment ratio is defined as $\frac{\bar{l}_i+\bar{l}_j+v}{b_i+b_j}$, where $\bar{l}_i + \bar{l}_j + v$ is the total amount of liquidity that the ECB decides to allocate. A parameter $v > 0$ ($v < 0$) means an overestimation (underestimation) by the ECB of the system's liquidity needs (see subsection 3.4).

[5] Instead of MROs, one could also consider, for instance, LTROs.

Denote by α_i the proportion of bank i's bid in terms of total bids: $\alpha_i = \frac{b_i}{b_i+b_j}$. In the primary market bank i is allocated with

$$l_i = \frac{\bar{l}_i + \bar{l}_j + \upsilon}{b_i + b_j} b_i = \alpha_i(\bar{l}_i + \bar{l}_j + \upsilon).$$

If this is insufficient to cover the liquidity needs, it still has to acquire

$$\bar{l}_i - l_i = \alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i \upsilon.$$

Bank j, in turn, buys

$$l_j = \frac{\bar{l}_i + \bar{l}_j + \upsilon}{b_i + b_j} b_j = \alpha_j(\bar{l}_i + \bar{l}_j + \upsilon)$$

in the primary market, and, if this amount exceeds its liquidity needs, it has an excess equal to

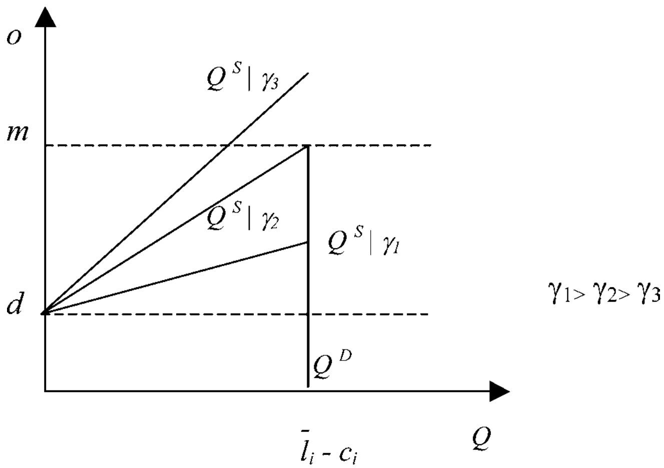
$$l_j - \bar{l}_j = \alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j \upsilon.$$

If collateral is not restrictive, bank i is not willing to buy liquidity in the secondary market at a price above m, the marginal lending rate. For prices below m it wants to fulfill all its needs, so the demand curve is given by

$$Q^D = \begin{cases} \alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i \upsilon \Leftarrow o \leq m \\ 0 \Leftarrow o > m. \end{cases}$$

In turn, banks of the j-type are not willing to sell their excess liquidity at a price below the deposit rate with the ECB. Their supply curve is assumed to be linear. I consider that, for precautionary motives related to uncertainty concerning the future evolution of primary rates, these banks may choose to retain some liquidity. This is modeled by an exogenous parameter $\gamma > 0$. In other words, γ stands for the "willingness" to lend. The inclusion of this parameter allows us to capture the possibility that i-banks are not able to acquire all the liquidity needed in the secondary market and have to make use of the lending facility. As figure 1 shows, this happens

Figure 1. Demand and Supply in the Interbank Market



for low-enough γ.[6] It should be stressed, however, that the main conclusions of the model as to the relative performance of fixed- and variable-rate tenders do not depend on the value of γ. The supply curve can be written as

$$Q^S = \begin{cases} 0 \Leftarrow o < d \\ \gamma(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j \upsilon) \frac{o-d}{m-d} \Leftarrow o \geq d. \end{cases}$$

Equating demand and supply, the equilibrium overnight rate arises:

$$o^* = \begin{cases} d + \frac{m-d}{\gamma} \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \\ m \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}. \end{cases}$$

[6]This happens, for example, in periods of high financial markets turbulence. In the limit, when γ tends to zero, the money market disappears and all liquidity must be obtained from the Central Bank. To set money markets to work again during the recent credit crisis, authorities announced that all interbank operations would be guaranteed by each State, up to a certain amount.

The quantity traded in the secondary market is

$$Q^* = \begin{cases} \alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i v \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \\ \gamma(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j v) \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}. \end{cases}$$

In the tertiary market there is no interaction between banks. Liquidity in short is obtained at m, and liquidity in excess gives rise to a deposit remunerated at d. Liquidity in short (for bank i) is

$$\bar{l}_i - l_i - Q^* = \begin{cases} 0 \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \\ (1-\gamma)(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j) - (\alpha_i + \gamma\alpha_j) v \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \end{cases}$$

and liquidity in excess (for bank j) is

$$l_j - \bar{l}_j - Q^* = \begin{cases} (\alpha_i + \alpha_j) v \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j} \\ (1-\gamma)(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j v) \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}. \end{cases}$$

Recall that $\alpha_i = \frac{b_i}{b_i + b_j}$. Then the problem of bank i in the primary market can be stated as

$$min_{b_i} \quad r\alpha_i(\bar{l}_i + \bar{l}_j + v) + \left(d + \frac{m-d}{\gamma} \frac{\alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i v}{\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j v}\right) \times (\alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i v) \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}$$

$$min_{b_i} \quad r\alpha_i(\bar{l}_i + \bar{l}_j + v) + m\gamma(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j v) \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}.$$

The problem of bank j is

$$min_{b_j} \quad r\alpha_j(\bar{l}_i + \bar{l}_j + v) - \left(d + \frac{m-d}{\gamma} \frac{\alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i v}{\alpha_j \bar{l}_i - \alpha_i \bar{l}_j + \alpha_j v}\right) \times (\alpha_j \bar{l}_i - \alpha_i \bar{l}_j - \alpha_i v) - d(\alpha_i + \alpha_j) v \Leftarrow \gamma > \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}$$

$$min_{bj} \quad r\alpha_j(\bar{l}_i + \bar{l}_j + \upsilon) - (\gamma m + (1-\gamma)d) \times (\alpha_j\bar{l}_i - \alpha_i\bar{l}_j + \alpha_j\upsilon) \Leftarrow \gamma \leq \frac{\bar{l}_i - l_i}{l_j - \bar{l}_j}.$$

To begin with, let us consider the simple case with $\upsilon = 0$ (the estimation of liquidity needs by the ECB is acute). This scenario is further elaborated by considering the possibilities of collateral shortage and credit rationing. I then present the changes in results when the ECB fails to correctly estimate the system's needs ($\upsilon \neq 0$).[7]

3.1 Absence of Estimation Errors

When the ECB correctly estimates the system's liquidity needs ($\upsilon = 0$), liquidity in excess matches liquidity in short for the interbank market. The equilibrium overnight rate is then

$$o^* = \begin{cases} d + \frac{m-d}{\gamma} \Leftarrow \gamma > 1 \\ m \Leftarrow \gamma \leq 1. \end{cases}$$

If $\gamma > 1$ (supply is sufficiently elastic so that all remaining liquidity needs of bank i may be satisfied in the secondary market), the problem of bank i resumes to

$$min_{b_i} \quad r\alpha_i(\bar{l}_i + \bar{l}_j) + \left(d + \frac{m-d}{\gamma}\right)(\alpha_j\bar{l}_i - \alpha_i\bar{l}_j)$$

and the problem of bank j to

$$min_{b_j} \quad r\alpha_j(\bar{l}_i + \bar{l}_j) - \left(d + \frac{m-d}{\gamma}\right)(\alpha_j\bar{l}_i - \alpha_i\bar{l}_j).$$

To be consistent with the assumption that i will not be a liquidity supplier and that j will not be a liquidity demander in the interbank market, their bids have to satisfy the following condition (arising from $Q^D \geq 0$ and $Q^S \geq 0$, with $\upsilon = 0$): $b_j\bar{l}_i - b_i\bar{l}_j \geq 0 \Leftrightarrow$

[7] Note that bidders have rational expectations, in the sense that they fully anticipate the Central Bank's allotment strategy.

$$b_i \leq \frac{\bar{l}_i}{\bar{l}_j} b_j$$

$$b_j \geq \frac{\bar{l}_j}{\bar{l}_i} b_i.$$

So, $b_i \in (0, \frac{\bar{l}_i}{\bar{l}_j} b_j]$, and $b_j \in [\frac{\bar{l}_j}{\bar{l}_i} b_i, +\infty)$. From this, the following is clear:

LEMMA 1. *In a fixed-rate tender without full allotment, bids can grow infinitely high, no matter what the expected position of the bank in the secondary market, which is at the origin of potentially low allotment ratios.*

This result confirms previous findings in the literature and is consistent with evidence from the first months of Stage Three of the EMU. It is not specific to the scenario under analysis ($\upsilon = 0$) and is a direct consequence of the fact that bids are not limited by available collateral—only the liquidity received is. As noted in the Introduction, a fixed-rate procedure with announced full allotment avoids this problem as well as the non-informativeness of bids as regards true funding requirements: banks just have to bid equal to their needs and the allotment ratio is simply equal to one.[8]

Optimizing the objective functions of i and j yields

$$(1 - \alpha_i)(\bar{l}_i + \bar{l}_j)(r - o)$$
$$(1 - \alpha_j)(\bar{l}_i + \bar{l}_j)(r - o).$$

If $o > r$ (which corresponds to $1 < \gamma < \frac{m-d}{r-d}$), the higher b_i, the better for bank i, and the higher b_j, the better for bank j, so bids will tend to reach very high levels. However, if γ is sufficiently high so that the equilibrium overnight rate falls below the MRO interest rate, both banks have an incentive to bid very low quantities in the MRO.

[8] Of course, in periods of high financial markets uncertainty, banks may be uncertain about their true liquidity needs and bid higher for precautionary motives.

The equilibrium locus is

$$b_i = \frac{\bar{l}_i}{\bar{l}_j} b_j.$$

The two reaction curves are upward sloping and fully coincide. There are multiple equilibria. The allotment ratio can thus turn out to be very low, if the equilibrium bids locate at high levels, which corresponds to the outcome of most MROs conducted through fixed-rate auctions at the beginning of Stage Three. This multiplicity of equilibria reduces (or even extinguishes) the informational content of bids as regards liquidity needs.

Bids of banks i and j are strategic complements: the higher the expectation of the bid of the rival, the higher the optimal bid of each bank. As expected, given the bid of the opponent, a bank's optimal bid is increasing in its own liquidity needs.

If $\gamma < 1$ ($\bar{l}_i - l_i$ is not entirely solved in the secondary market) or $\gamma = 1$, the problem of bank i can be written as

$$min_{b_i} \quad r\alpha_i(\bar{l}_i + \bar{l}_j) + m(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j)$$

and the problem of bank j as

$$min_{b_j} \quad r\alpha_j(\bar{l}_i + \bar{l}_j) - (\gamma m + (1-\gamma)d)(\alpha_j \bar{l}_i - \alpha_i \bar{l}_j).$$

Differentiating with respect to own bid,

$$(1-\alpha_i)(\bar{l}_i + \bar{l}_j)(r-m) < 0$$
$$(1-\alpha_j)(\bar{l}_i + \bar{l}_j)(r-d-\gamma(m-d)).$$

For bank i, the higher b_i, the better, which is quite intuitive from the fact that the overnight rate will reach m. If $\frac{r-d}{m-d} < \gamma < 1$, bank j also wants to bid high in the first market, but for low-enough γ this result may be reversed, as j will be left with much liquidity to deposit with the ECB. The equilibrium locus is again given by $b_i = \frac{\bar{l}_i}{\bar{l}_j} b_j$, and the allotment ratio may reach very low levels.

Note that in periods of high turbulence γ will tend to zero, corresponding to the vanishing of liquidity supply in the money market. In these circumstances i-banks will bid very high in the primary market, but not j-banks.

3.2 Collateral Shortage

Suppose now that bank i is limited by its amount c_i of collateral, such that $c_i < \bar{l}_i$. Bank i will try to acquire an amount equal to c_i (the maximum allowed) in the primary market.[9] In the secondary market the supply curve does not change and the demand curve is perfectly inelastic, with

$$Q^D = \bar{l}_i - c_i.$$

Because of collateral shortage, bank i has to fully satisfy Q^D. The equilibrium overnight rate may thus be higher than m and will be given by

$$o^* = d + \frac{(m-d)}{\gamma} \frac{\bar{l}_i - c_i}{\alpha_j \bar{l}_i - \alpha_i \bar{l}_j}.$$

A lower c_i increases the likelihood of o^* rising above m.

In the tertiary market, bank j deposits

$$\alpha_j(\bar{l}_i + \bar{l}_j) - \bar{l}_j - Q^S = c_i - \alpha_i(\bar{l}_i + \bar{l}_j),$$

which varies positively with c_i: shortage of collateral (lower c_i) intensifies trading in the interbank market, and so less liquidity remains to be placed at d.

In order for i to guarantee itself an amount of liquidity equal to c_i in the primary market, its minimum bid is $b_i^{min} = \frac{c_i}{\bar{l}_i + \bar{l}_j - c_i} b_j$, arising from the condition $\alpha_i(\bar{l}_i + \bar{l}_j) \geq c_i$. This is actually the optimal bid, since the objective function appears to be increasing in b_i. It does not benefit bank i to make a bid above this one, since that would not assure any additional liquidity in the primary market and would increase the prevailing interest rate in the secondary market (because bank j would be allocated with less liquidity in the MRO).

So, bidding equilibria are now given by the relationship $b_i = \frac{c_i}{\bar{l}_i + \bar{l}_j - c_i} b_j$. In equilibrium the shortage of funds for i, equal to $\bar{l}_i - c_i$, is solved in the secondary market, at an interest rate equal to $d + \frac{m-d}{\gamma}$.

[9]There is no point in saving collateral for the third market, because the price of liquidity is higher than in the MRO.

LEMMA 2. *Lack of enough collateral to cover the allotted amount in the primary market raises price and quantity traded in the interbank market, whereas the use of the deposit facility decreases.*

To fulfill its liquidity needs, bank i spends $rc_i+(d+\frac{m-d}{\gamma})(\bar{l}_i-c_i)$, higher than in the case in which collateral is not restrictive if γ is low enough ($\gamma < \frac{m-d}{r-d}$), the most likely scenario under a credit crisis. For this range of values of γ, bank j is able to take advantage of i's shortage of collateral, and its expenses decline. The ECB's revenues, in turn, remain unchanged as compared with the case of unbinding collateral.[10] The total amount spent by i and j together is not altered (so there is no loss of efficiency), but the distribution may change in favor of the banks that are not restricted by collateral.

3.3 Credit Rationing in the Interbank Market

Let us admit that, because of information problems related with the repayment capacity of the borrower, banks of type j are not willing to lend at an overnight rate higher than t, with $d < t < m$ (recall that transactions in the interbank market are uncollateralized). Banks of type i are thus subject to credit rationing in the secondary market. Rationing may also occur because of bank j's uncertainty about future own liquidity needs. I elaborate on the case with collateral restrictions, so in the equilibrium i-banks will use all the collateral in the primary market. This is the most relevant scenario under financial market turmoil.

In this case equilibrium bids are again given by $b_i = \frac{c_i}{\bar{l}_i+\bar{l}_j-c_i}b_j$. Quantity traded in the interbank market, at the interest rate t, is equal to $\frac{\gamma(t-d)(\bar{l}_i-c_i)}{m-d}$. As expected, it varies positively with t: the more rationing there is (the lower t), the lower Q. Credit rationing is active if and only if $t < d + \frac{m-d}{\gamma}$, the equilibrium overnight rate obtained before.

Bank i is unable to satisfy reserve requirements by an amount equal to what bank j deposits with the ECB. This amount varies positively with the level of rationing and negatively with γ, as expected.

[10]The reference to the ECB's revenues is just a remark. The Central Bank has mainly policy concerns.

LEMMA 3. *Due to the existence of rationing in the interbank market, banks that are restricted by collateral may be unable to satisfy their liquidity needs. In turn, the other banks have excess liquidity.*

This excess liquidity may be applied through the deposit facility or it may also be absorbed through the ECB's fine-tuning operations, which occurred frequently since the beginning of the recent financial market turmoil.

The credit-rationing situation could also be addressed, with identical conclusions, by looking at the parameter γ. In case credit institutions effectively suspend interbank transactions (γ tends to zero), an extreme rationing situation that characterizes markets during periods of high turbulence, an expansion in the set of eligible assets for collateral purposes may be necessary for banks of type i to be able to meet their liquidity needs, through the Central Bank's providing operations (recall the biennial review of September 4, 2008). Notice that as γ approaches zero, the expenses of a bank with binding collateral grow significantly (see last subsection).

3.4 Estimation Errors

In this subsection the hypothesis that $\upsilon = 0$ is abandoned. The ECB may underestimate ($\upsilon < 0$) or overestimate ($\upsilon > 0$) the system's liquidity needs, which is quite plausible in a period of financial turmoil and sharp liquidity tensions. This case (with no collateral restrictions) corresponds to the general problem formulated in the beginning of the section. The wrong estimation derives from an incorrect forecast of the "autonomous factors" of liquidity injection/absorption and affects banks of both types (i and j).[11]

Suppose that $\upsilon < 0$. Then it can be seen that bank i is allocated a quantity equal to $\bar{l}_i + \upsilon$ (below its needs), while bank j receives $\bar{l}_j$. So, i is the one that bears all the burden of the ECB's estimation

[11]The autonomous liquidity factors of the euro area are the Eurosystem's balance-sheet items whose amount is independent of the monetary policy operations of the Central Bank and comprise, namely, banknotes in circulation, government deposits, and net foreign assets. Note that under a fixed-rate tender with full allotment format, there is no need to estimate the system's needs, because the banks' bids truly reveal them, so $\upsilon = 0$.

error. As a consequence, it will have to acquire $|v|$ through the lending facility; total expenses are higher than without estimation errors (if i is restricted by collateral, it may be unable to comply with reserve requirements). Bank j's expenses, in turn, are unaffected. The ECB benefits from the underestimation of liquidity needs, since its revenue rises by $(m - r)|v|$.

These results are reverted when liquidity needs are overestimated ($v > 0$). Then equilibrium bids satisfy $b_i = \frac{\bar{l}_i}{\bar{l}_j + v} b_j$, bank i is allocated with its full needs, and bank j receives v in excess, which it will deposit with the ECB. Expenses of bank i are left unchanged as compared with the case with $v = 0$, but bank j's expenses rise. ECB's revenues are again larger than without estimation errors. The ECB always benefits from $v \neq 0$, because the estimation error will have to be corrected through the "standing facilities."

LEMMA 4. *When the ECB underestimates (overestimates) the system's liquidity needs, net demanders (suppliers) in the interbank market bear the burden of this estimation error.*

4. Variable-Rate Tenders

In variable-rate tenders, banks have two decision variables: the amount they propose to buy (as in a fixed-rate auction) and the interest rate they propose to pay.

The bank offering the highest interest rate wins the auction and receives a liquidity amount equal to its bid. The loser is left with the remaining liquidity (or, more precisely, with the minimum between the remaining liquidity and available collateral). I assume that each bank pays its own interest rate bid—multiple-rate auction, the procedure adopted by the Eurosystem.

Consider that the ECB wishes to allocate $\bar{l}_i + \bar{l}_j + v$, as before, with $v < 0$ corresponding to an underestimation of the system's needs. Denote by r_i (r_j) the interest rate bid of bank i (j). Then, liquidity allocated to each counterpart is the following:[12]

[12]When $r_i = r_j$ (both banks bid the same price), each one receives a proportion of the liquidity injection corresponding to the quantity bid made, as in a fixed-rate tender without full allotment.

$$l_i = \begin{cases} b_i \Leftarrow r_i > r_j \\ \bar{l}_i + \bar{l}_j + \upsilon - b_j \Leftarrow r_i < r_j \end{cases}$$

$$l_j = \begin{cases} \bar{l}_i + \bar{l}_j + \upsilon - b_i \Leftarrow r_i > r_j \\ b_j \Leftarrow r_i < r_j. \end{cases}$$

Liquidity in short for bank i is

$$\bar{l}_i - l_i = \begin{cases} \bar{l}_i - b_i \Leftarrow r_i > r_j \\ b_j - \bar{l}_j - \upsilon \Leftarrow r_i < r_j \end{cases}$$

and in excess for bank j is

$$l_j - \bar{l}_j = \begin{cases} \bar{l}_i + \upsilon - b_i \Leftarrow r_i > r_j \\ b_j - \bar{l}_j \Leftarrow r_i < r_j. \end{cases}$$

When bank i wins the auction ($r_i > r_j$), demand and supply in the interbank market (with no collateral restrictions for i) are

$$Q^D = \begin{cases} \bar{l}_i - b_i \Leftarrow o \leq m \\ 0 \Leftarrow o > m \end{cases}$$

$$Q^S = \begin{cases} 0 \Leftarrow o < d \\ \gamma(\bar{l}_i - b_i + \upsilon)\frac{o-d}{m-d} \Leftarrow o \geq d, \end{cases}$$

so the equilibrium overnight rate is

$$o^* = \begin{cases} d + \frac{m-d}{\gamma}\frac{\bar{l}_i - b_i}{\bar{l}_i - b_i + \upsilon} \Leftarrow \gamma > \frac{\bar{l}_i - b_i}{\bar{l}_i - b_i + \upsilon} \\ m \Leftarrow \gamma \leq \frac{\bar{l}_i - b_i}{\bar{l}_i - b_i + \upsilon} \end{cases}$$

and quantity traded is

$$Q^* = \begin{cases} \bar{l}_i - b_i \Leftarrow \gamma > \frac{\bar{l}_i - b_i}{\bar{l}_i - b_i + \upsilon} \\ \gamma(\bar{l}_i - b_i + \upsilon) \Leftarrow \gamma \leq \frac{\bar{l}_i - b_i}{\bar{l}_i - b_i + \upsilon}. \end{cases}$$

When the winner is bank j $(r_i < r_j)$, the following changes occur:

$$Q^D = \begin{cases} b_j - \bar{l}_j - \upsilon \Leftarrow o \leq m \\ 0 \Leftarrow o > m \end{cases}$$

$$Q^S = \begin{cases} 0 \Leftarrow o < d \\ \gamma(b_j - \bar{l}_j)\frac{o-d}{m-d} \Leftarrow o \geq d, \end{cases}$$

so the equilibrium overnight rate is

$$o^* = \begin{cases} d + \frac{m-d}{\gamma}\frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \Leftarrow \gamma > \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \\ m \Leftarrow \gamma \leq \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \end{cases}$$

and quantity traded is

$$Q^* = \begin{cases} b_j - \bar{l}_j - \upsilon \Leftarrow \gamma > \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \\ \gamma(b_j - \bar{l}_j) \Leftarrow \gamma \leq \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j}. \end{cases}$$

Therefore bank i has to resort to the lending facility for

$$\bar{l}_i - b_i - Q^* = \begin{cases} 0 \Leftarrow \gamma > \frac{\bar{l}_i-b_i}{\bar{l}_i-b_i+\upsilon} \\ (1-\gamma)(\bar{l}_i - b_i) - \gamma\upsilon \Leftarrow \gamma \leq \frac{\bar{l}_i-b_i}{\bar{l}_i-b_i+\upsilon} \end{cases}$$

when $r_i > r_j$, and for

$$\bar{l}_i - b_i - Q^* = \begin{cases} 0 \Leftarrow \gamma > \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \\ (1-\gamma)(b_j - \bar{l}_j) - \upsilon \Leftarrow \gamma \leq \frac{b_j-\bar{l}_j-\upsilon}{b_j-\bar{l}_j} \end{cases}$$

when $r_i < r_j$. Bank j, in turn, deposits

$$l_j - \bar{l}_j - Q^* = \begin{cases} \upsilon \Leftarrow \gamma > \frac{\bar{l}_i-b_i}{\bar{l}_i-b_i+\upsilon} \\ (1-\gamma)(\bar{l}_i - b_i + \upsilon) \Leftarrow \gamma \leq \frac{\bar{l}_i-b_i}{\bar{l}_i-b_i+\upsilon} \end{cases}$$

when $r_i > r_j$, and

$$l_j - \bar{l}_j - Q^* = \begin{cases} \upsilon \Leftarrow \gamma > \frac{b_j - \bar{l}_j - \upsilon}{b_j - \bar{l}_j} \\ (1-\gamma)(b_j - \bar{l}_j) \Leftarrow \gamma \leq \frac{b_j - \bar{l}_j - \upsilon}{b_j - \bar{l}_j} \end{cases}$$

when $r_i < r_j$.

Consider the case of a pure variable-rate tender, in which bids are distributed in the interval $[d, m]$.[13] In a subsection below, these results will be particularized to variable-rate tenders with a minimum bid higher than d, the scenario adopted by the ECB. As we will see, qualitative findings do not change.

If one assumes a uniform distribution for interest rate bids, the probability for bank i of winning the auction is given by $\Pr(r_j < r_i) = \frac{r_i - d}{m - d}$. For bank j, in turn, the probability of winning is $\frac{r_j - d}{m - d}$. Each bank minimizes in its own price and quantity bids a weighted average of the expenses in the winning and in the losing cases. The weights are the probabilities above.

The solution of each bank's optimization problem gives rise to the optimal b_i, b_j, r_i, and r_j, which, once replaced in the equilibrium expressions above for the interbank market and for the standing facilities, allow us to obtain the complete solution of the reserve-keeping problem. As in the analysis of fixed-rate tenders, I begin with the case of $\upsilon = 0$.

4.1 Absence of Estimation Errors

When the ECB has a precise estimation of the system's liquidity needs ($\upsilon = 0$), the conditions imposed on b_i and b_j such that in equilibrium bank i is not a supplier in the interbank market and bank j is not a demander imply that $b_i \in (0, \bar{l}_i]$ and $b_j \in [\bar{l}_j, \bar{l}_i + \bar{l}_j]$. Note that, contrary to what happens in a fixed-rate auction, b_i and b_j have finite superior limits. This prevents the allotment ratio from falling to very low levels.

Interior solutions for r_i and r_j require that aggregate bidding behavior exceeds aggregate liquidity needs ($b_i + b_j > \bar{l}_i + \bar{l}_j$), which

[13] It does not pay to bid an interest rate higher than m, because the bank can obtain liquidity at m through the lending facility. Also, the Central Bank is not willing to accept bids below d, since banks can deposit liquidity at d.

corresponds to rationing at the marginal rate, a situation that occurred in almost all variable-rate tenders conducted.

When $\upsilon = 0$ the cut-off level for γ so that the equilibrium overnight rate does not rise above m is simply equal to 1. The optimization problems of banks i and j for $\gamma > 1$ ($o^* < m$) resume to

$$
\begin{aligned}
&min_{b_i,r_i}\left(\frac{r_i-d}{m-d}\right)\left(r_ib_i+\left(d+\frac{m-d}{\gamma}\right)(\bar{l}_i-b_i)\right)\\
&\qquad+\left(\frac{m-r_i}{m-d}\right)\left(r_i(\bar{l}_i+\bar{l}_j-b_j)+\left(d+\frac{m-d}{\gamma}\right)(b_j-\bar{l}_j)\right)\\
&min_{b_j,r_j}\left(\frac{m-r_j}{m-d}\right)\left(r_j(\bar{l}_i+\bar{l}_j-b_i)-\left(d+\frac{m-d}{\gamma}\right)(\bar{l}_i-b_i)\right)\\
&\qquad+\left(\frac{r_j-d}{m-d}\right)\left(r_jb_j-\left(d+\frac{m-d}{\gamma}\right)(b_j-\bar{l}_j)\right).
\end{aligned}
$$

For $\gamma \leq 1$ these optimization problems are

$$
\begin{aligned}
&min_{b_i,r_i}\left(\frac{r_i-d}{m-d}\right)(r_ib_i+m(\bar{l}_i-b_i))\\
&\qquad+\left(\frac{m-r_i}{m-d}\right)(r_i(\bar{l}_i+\bar{l}_j-b_j)+m(b_j-\bar{l}_j))\\
&min_{bj,r_j}\left(\frac{m-r_j}{m-d}\right)(r_j(\bar{l}_i+\bar{l}_j-b_i)-(m\gamma+d(1-\gamma))(\bar{l}_i-b_i))\\
&\qquad+\left(\frac{r_j-d}{m-d}\right)(r_jb_j-(m\gamma+d(1-\gamma))(b_j-\bar{l}_j)).
\end{aligned}
$$

There are four equilibria for the variable-rate tender when $\gamma > 1$. The only equilibrium with both types of banks participating in the MRO and interior solutions for the price bids is[14]

[14]There are three other equilibria, which do not comply with the condition $b_i + b_j > \bar{l}_i + \bar{l}_j$, so do not have rationing at the marginal rate.

$$b_i^* = \bar{l}_i,\ r_i^* = d + \frac{m-d}{2\gamma}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = \begin{cases} d + \frac{m-d}{2\gamma} - \frac{(m-d)\bar{l}_j}{2\bar{l}_i} \Leftarrow \bar{l}_j \leq \frac{\bar{l}_i}{\gamma} \\ d \Leftarrow \bar{l}_j > \frac{\bar{l}_i}{\gamma}. \end{cases}$$

In this equilibrium bank i wins the auction ($r_i > r_j\ \forall\ \bar{l}_i, \bar{l}_j$)[15] and is allocated with all the liquidity it needs. Bank j also receives all the liquidity required (it receives $\bar{l}_i + \bar{l}_j - \bar{l}_i = \bar{l}_j$, even though it bids higher) but pays a lower interest rate, declining in its own liquidity needs and rising in the rival's, such that when $\bar{l}_i$ is sufficiently small relative to $\bar{l}_j$, bank j is not willing to make a price offer above the minimum (d). The bank that expects to have a demand position in the interbank market is the one that makes the lowest quantity bid; however, it is the one that wins, so bidding an amount equal to its needs is the optimal behavior.

For $\gamma \leq 1$, the relevant case under a financial markets crisis scenario, the only equilibrium with interior solutions for the interest rate bids is[16]

$$b_i^* = \bar{l}_i,\ r_i^* = \frac{m+d}{2}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = \begin{cases} d + \frac{(m-d)\gamma}{2} - \frac{(m-d)\bar{l}_j}{2\bar{l}_i} \Leftarrow \bar{l}_j \leq \gamma\bar{l}_i \\ d \Leftarrow \bar{l}_j > \gamma\bar{l}_i. \end{cases}$$

Bank i is the winner and pays an interest rate independent of γ, because unsatisfied liquidity will have to be paid at m. The price offered by j declines as γ increases, for the more inelastic is supply, the less bank j will be able to sell in the money market (at a rate equal to m), and hence the more it will have to deposit at d. In the limit, as γ tends to zero (interbank market vanishing), r_j^* will tend to d, the minimum bid allowed in this scenario (see subsection 4.4 for a higher minimum bid).

[15] The bank with the worst expectations about its position in the secondary market is the one that bids the highest price.

[16] There is another equilibrium, which does not comply with the condition $b_i + b_j > \bar{l}_i + \bar{l}_j$.

These results allow us to state the following lemma, which contrasts with lemma 1.

LEMMA 5. *The equilibrium quantity bid in a variable-rate tender is finite. The equilibrium allotment ratio is equal to* $\frac{\bar{l}_i+\bar{l}_j}{2\bar{l}_i+\bar{l}_j}$, *which is growing in the liquidity needs of banks that expect not to be demanders in the secondary market, and decreasing in the liquidity needs of banks that expect not to be suppliers. In the context of this model, the allotment ratio is higher than* $\frac{1}{2}$.

Furthermore, the finite number of equilibrium quantity bids in a variable-rate tender is a clear difference as compared with the outcome of fixed-rate tenders (without full allotment). The informational role of quantity bids (in conjunction with price bids) regarding liquidity needs is preserved.

4.2 Collateral Shortage

Assume now that i is limited by the collateral amount c_i, such that $c_i < \bar{l}_i$. Under these circumstances bank i will bid in such a way that available collateral is fully used in the primary market, as in the fixed-rate tender. The overnight rate may rise above m. I consider that collateral is restrictive both when i wins and when it loses the auction.[17] For all γ, demand in the interbank market is

$$Q^D = \bar{l}_i - c_i,$$

while supply is given by

$$Q^S = \begin{cases} 0 \Leftarrow o < d \\ \gamma(\bar{l}_i - c_i)\frac{o-d}{m-d} \Leftarrow o \geq d \end{cases}$$

if i wins the auction, and by

$$Q^S = \begin{cases} 0 \Leftarrow o < d \\ \gamma(b_j - \bar{l}_j)\frac{o-d}{m-d} \Leftarrow o \geq d \end{cases}$$

if the winner is j.

[17] So, when i loses, it does not buy $\bar{l}_i + \bar{l}_j - b_j$, but just c_i, exactly the same amount bought when it wins.

In the equilibrium of this game, the interest rate paid by j is higher the more i is restricted by collateral. When i wins the auction, its shortage of funds is solved in the secondary market at an interest rate equal to $d + \frac{m-d}{\gamma}$;[18] when it loses, the interbank interest rate is higher.

LEMMA 6. *In the equilibrium of a variable-rate tender with collateral restrictions for bank i, interest rate bids of j in the primary market are rising in i's shortage of collateral.*

There are multiple equilibria for the quantity bidding behavior of i. The focal equilibrium is $b_i^* = c_i$, under which the allotment ratio is higher than with no collateral restrictions, because now i bids below its needs. The choice of $b_i^* = c_i$ is also related to the fact that, in the practice of the Eurosystem, bids which show up to be impossible to cover with collateral are highly penalized.

4.3 Credit Rationing in the Interbank Market

Consider now that, due to information problems, the liquidity supplier in the secondary market, j, decides to ration credit at the interest rate t, with $d < t < m$. Rationing may also occur because of uncertainty related to future own liquidity needs. Then the equilibrium of the game with both banks participating in the auction and interior solutions for the interest rate bids, $v = 0$, and no collateral restrictions becomes

$$b_i^* = \bar{l}_i,\ r_i^* = \frac{m+d}{2} - \gamma\frac{(t-d)(m-t)}{2(m-d)}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = d + \gamma\frac{(t-d)^2}{2(m-d)} - \frac{(m-d)\bar{l}_j}{2\bar{l}_i}.$$

Note that $\frac{\partial r_i^*}{\partial t} < 0$ is true only for $t < \frac{m+d}{2}$. This inequality is valid whenever $\gamma > 2$, so for high-enough elasticity of supply, the loss in terms of quantity acquired in the interbank market (and that

[18] The value of c_i has no influence on o^* because there is a shift in supply associated with the shift in demand due to collateral shortage, so that o^* remains unchanged.

has to be transferred to the lending facility at a penalty rate) is important and induces a more aggressive price-bidding behavior in the MRO. If supply is not so elastic, then the reduction in quantity traded is more modest and the rise in the price bid of i occurs only if rationing is sufficiently relevant. Comparing with the corresponding equilibrium with no rationing, we state the following:

LEMMA 7. *Credit rationing in the secondary market gives rise to a decline in the interest rate bid of the bank that is a supplier in that market. The price bid made by the demander may rise or fall, depending on the elasticity of supply being high or low, respectively.*

Of course, under extreme credit rationing such as in the recent crisis, t is lower than $\frac{m+d}{2}$, so the interest rate bid of i-banks will tend to be very high. Observation of marginal rates in MROs actually shows a gap relative to the minimum bid that is larger during the turbulence than before it.

4.4 Minimum Bid for the Interest Rate

In the analysis conducted so far, the lower bound for the price offers has been d. When the change to variable-rate tenders occurred in June 2000, the minimum bid was set at the fixed rate in use in the MROs of the Eurosystem at the time of the change—that is, r in our notation. In these circumstances r_i and r_j are now free to fluctuate in the interval $[r, m]$ instead of $[d, m]$. The equilibrium for $\gamma > 1$ with both types of banks participating in the MRO and with interior solutions for the price bids becomes

$$b_i^* = \bar{l}_i,\ r_i^* = \begin{cases} \frac{d+r}{2} + \frac{m-d}{2\gamma} \Leftarrow \gamma > \frac{m-d}{r-d} \\ r \Leftarrow \gamma \geq \frac{m-d}{r-d} \end{cases}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = \begin{cases} \frac{d+r}{2} + \frac{m-d}{2\gamma} - \frac{(m-r)\bar{l}_j}{2\bar{l}_i} \Leftarrow \bar{l}_j < \frac{(m-d-\gamma(r-d))\bar{l}_i}{\gamma(m-r)} \\ r \Leftarrow \bar{l}_j \geq \frac{(m-d-\gamma(r-d))\bar{l}_i}{\gamma(m-r)}. \end{cases}$$

The interest rates paid by both banks rise as compared with the no-minimum-bid situation. Hence their expenses rise as well, as do the ECB's revenues. The winning price bid is mostly influenced by the minimum level r, the interest rate on the deposit facility being the one with the lowest impact on r_i^* if the elasticity of supply is not too high ($\gamma < 2$); otherwise, the lending facility rate has the lowest impact.

When $\gamma \leq 1$, this equilibrium is

$$b_i^* = \bar{l}_i,\ r_i^* = \frac{m+r}{2}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = \begin{cases} \frac{d+r}{2} + \frac{(m-d)\gamma}{2} - \frac{(m-r)\bar{l}_j}{2\bar{l}_i} \Leftarrow \bar{l}_j \leq \frac{((m-d)\gamma-(r-d))\bar{l}_i}{m-r} \\ r \Leftarrow \bar{l}_j > \frac{((m-d)\gamma-(r-d))\bar{l}_i}{m-r}. \end{cases}$$

Interest bids are again higher than in the absence of a minimum bid. The winning bank offers a price equal to the midpoint of the allowed interval, just as in the no-minimum-bid case. The value of γ does not influence this bid, because the interbank rate is predetermined at m, contrary to what happens when $\gamma > 1$.

A variable-rate tender with a minimum price bid has no qualitative difference from a pure variable-rate tender. When the signaling effect of the minimum offer as to the monetary policy stance can be achieved through some other vehicle (for instance, by announcing an operational target), the choice of the instrument is irrelevant.

4.5 Estimation Errors

When the ECB fails to correctly estimate the system's liquidity needs,[19] it can be seen that bank i will find it more expensive to comply with reserve requirements if $\upsilon < 0$ (underestimation), and cheaper if $\upsilon > 0$ (overestimation). The interest rate paid rises in the former situation as compared with the correct estimation case, and declines in the latter. There is an additional reason for bank i's expenses to grow in the underestimation case—the fact that it will have to resort to the lending facility for the amount $|\upsilon|$.

As to bank j, a negative estimation error has no effect on the price paid, but $\upsilon > 0$ implies a lower price offer. This bank makes use of the deposit facility (for an amount equal to the estimation error) when $\upsilon > 0$.

[19] As in fixed-rate tenders, this wrong estimation is related to the absorption or injection of liquidity by "autonomous factors."

The equilibria characterized by interior solutions for the overnight rate and by both banks participating in the MRO and making interior price bids (with no minimum rate) are as follows. For $\upsilon < 0$

$$b_i^* = \bar{l}_i + \upsilon,\ r_i^* = d + \frac{m-d}{2\gamma} - \frac{\upsilon(m-d)}{2\bar{l}_i}$$

$$b_j^* = \bar{l}_i + \bar{l}_j,\ r_j^* = \begin{cases} d + \frac{m-d}{2\gamma} - \frac{(m-d)\bar{l}_j}{2\bar{l}_i} \Leftarrow \bar{l}_j \leq \frac{\bar{l}_i}{\gamma} \\ d \Leftarrow \bar{l}_j > \frac{\bar{l}_i}{\gamma} \end{cases}$$

and for $\upsilon > 0$

$$b_i^* = \bar{l}_i,\ r_i^* = d + \frac{(m-d)\bar{l}_i}{2\gamma(\bar{l}_i + \upsilon)}$$

$$b_j^* = \bar{l}_i + \bar{l}_j + \upsilon,\ r_j^* = \begin{cases} d + \frac{(m-d)\bar{l}_i}{2\gamma(\bar{l}_i+\upsilon)} - \frac{(m-d)(\bar{l}_j+\upsilon)}{2\bar{l}_i} \Leftarrow \bar{l}_j \leq \frac{\bar{l}_i^2}{\gamma(\bar{l}_i+\upsilon)} - \upsilon \\ d \Leftarrow \bar{l}_j > \frac{\bar{l}_i^2}{\gamma(\bar{l}_i+\upsilon)} - \upsilon. \end{cases}$$

The bank which expects not to be a liquidity supplier in the secondary market reduces its quantity bid as compared with the no-estimation-error case when $\upsilon < 0$, and the bank which expects not to be a liquidity demander raises its bid when $\upsilon > 0$. In these circumstances expectations as to net positions in the interbank market are fulfilled. Deviations as to liquidity needs are fully corrected through the ECB's standing facilities. As stated above, bank i is harmed, in terms of expenses, by underestimation, and benefits from overestimation. Bank j is unaffected by underestimation; when there is overestimation, results are ambiguous and depend, among other factors, on the magnitude of υ (on the one hand, the price paid in the MRO is reduced as compared with the $\upsilon = 0$ case, but liquidity acquired is higher, and there is a surplus to be deposited at d).

In these equilibria the allotment ratio is $\frac{\bar{l}_i+\bar{l}_j+\upsilon}{2\bar{l}_i+\bar{l}_j+\upsilon}$. So, underestimation of the system's liquidity needs decreases this ratio, whereas overestimation raises it.

LEMMA 8. *An underestimation (overestimation) by the ECB of the system's liquidity needs raises (decreases) the interest rate bid of* *banks which expect to be liquidity demanders in the secondary market and their expenses, and decreases (raises) the allotment ratio.*

5. Fixed- versus Variable-Rate Tenders

The model presented is a simple three-stage game in which banks try to obtain the liquidity needed by making use of open-market operations of the ECB, the interbank money market, and "standing facilities." Although simple, the model replicates empirical facts observed since the beginning of Stage Three of the EMU, confirms some results in the literature, and allows us to address the possible implications of some facts deriving from the recent credit crisis, such as collateral shortage, credit rationing in the interbank market, and wrong estimation by the ECB of the system's true liquidity needs. This section summarizes some of the results obtained.

Confirming observation and previous literature results, low allotment ratios were shown to be inherent to fixed-rate tenders (without full allotment), since bids may reach very high levels. On the contrary, variable-rate tenders allow for reasonable levels of this ratio. Overbidding may be present in both types of auction; however, it may be a much more serious problem in the former than in the latter (the change from fixed- to variable-rate procedures in June 2000 has indeed led to clearly higher allotment ratios).

The informational content of quantity bids as regards true liquidity needs is lost in fixed-rate tenders (without full allotment), due to multiplicity of equilibria. However, it is preserved in variable-rate tenders.

In a variable-rate tender banks have a higher probability of being allocated with all the liquidity needed in the MRO.[20] This is especially important for those institutions that expect to be in a demand position in the interbank market and even more when this market is highly restricted or does not even work. Actually, in a fixed-rate tender liquidity allocated to each counterpart is a function of its own quantity bid and also of the rival's, so that a perception error about the latter may leave the bank in a weak position thereafter; on the

[20] Again, this is as compared with a fixed-rate tender without full allotment. If fixed-rate tenders have full allotment, the probability of being allocated with all the liquidity needed is one.

contrary, in a variable-rate tender the bank may guarantee itself the desired liquidity as long as it makes a sufficiently high price bid.

Suppose that i believes that j will bid b_{j1} and therefore, in a fixed-rate tender (with no distortions—binding collateral and other), chooses $b_{i1} = \frac{\bar{l}_i}{\bar{l}_j} b_{j1}$, but j actually bids $b_{j2} > b_{j1}$. Then bank i will receive $\frac{\bar{l}_i+\bar{l}_j}{b_{i1}+b_{j2}} b_{i1} < \frac{\bar{l}_i+\bar{l}_j}{b_{i1}+b_{j1}} b_{i1}$ and j will obtain $\frac{\bar{l}_i+\bar{l}_j}{b_{i1}+b_{j2}} b_{j2} > \frac{\bar{l}_i+\bar{l}_j}{b_{i1}+b_{j1}} b_{j1}$. What j receives in excess is exactly what i is short of; this misallocation is corrected in the secondary market at an (interior) interbank rate equal to $d + \frac{m-d}{\gamma}$. For sufficiently low γ ($\gamma < \frac{m-d}{r-d}$), j benefits in terms of expenses and i is harmed, the reverse being true for high γ. In any case, the ECB's revenues are unaffected by this perception error of bank i.

In a variable-rate tender (again with no distortions) the winning bank is not harmed by a wrong perception of the rival's bid. The loser, however, may suffer from an incorrect perception of the other's liquidity needs (and hence quantity bid), both in what concerns allotted amount and price paid.

For banks restricted by collateral, a relevant scenario under the recent financial turmoil, bidding mistakes (above the equilibrium) are more harmful under fixed-rate procedures than under variable-rate procedures. As we have seen, the equilibrium quantity bid for bank i is $\frac{c_i}{\bar{l}_i+\bar{l}_j-c_i} b_j$ in a fixed-rate tender and c_i in a variable-rate one. Bidding above the equilibrium implies less liquidity for bank j in the fixed-rate auction, and hence a rise in the interbank market rate; in a variable-rate auction, on the contrary, liquidity received by j is unaffected by b_i, so in this sense bank i's situation is not worsened.

Shortage of collateral to cover liquidity needs may benefit banks on the supply side of the secondary market. The revenues of the ECB are unaffected by collateral shortage in a fixed-rate tender but may rise in variable-rate tenders, because price bids of unrestricted banks are higher.

The existence of credit rationing in the interbank market, another relevant scenario under intensified market tensions, accompanied by shortage of collateral of the bank which will be in a demand position in that market, leaves this institution with unsatisfied liquidity needs in both procedures. In turn, there is excess liquidity to be absorbed by the ECB, as evidence on the high frequency of fine-tuning operations during the credit crisis has confirmed. Under a variable-rate procedure, and with interbank credit rationing, banks will tend to bid high interest rates in the primary market, therefore leading to an enlarged differencial between the marginal rate and the minimum bid, as also observed.

Estimation errors by the ECB have clearer effects on banks' expenses under a fixed-rate procedure than under a variable-rate one. In the former, banks with a demand position in the secondary market are hurt by underestimation of liquidity needs and are unaffected by overestimation; the reverse happens for banks with a supply position. In a variable-rate auction, underestimation has the same implications as in the fixed-rate auction; however, banks with a demand position may benefit from an ECB's overestimation of the system's needs, while the impact of this mistake on the expenses of the banks with a supply position is ambiguous.

Taking into account the variety of procedures that have been used to stabilize the markets during the recent turmoil, the debate on the virtues and drawbacks of fixed- and variable-rate tenders gained new relevance. However, as we have seen, the results in this paper still favor the choice of variable-rate procedures as opposed to no-full-allotment fixed-rate tenders.

6. Conclusion

Open-market operations are an important instrument of the ECB's monetary policy. Most of them have been historically conducted through variable-rate tenders, although fixed-rate operations have already been in practice and have never been definitely excluded. Actually, the Central Bank returned to the fixed-rate format, but with full allotment, to conduct its MROs from October 9, 2008 on. During the financial market turmoil that emerged in the summer of 2007 and intensified later on, the ECB made use of several liquidity management instruments, and a comparative analysis of both types of tenders is pertinent, under relevant scenarios such as the possibility that collateral is binding, rationing by suppliers in the interbank market (due to uncertainty as to other institutions' solvency and own need of funds), and estimation errors of the system's true needs by the monetary authority. Recovering some previous results in the literature, this paper has compared fixed- and variable-rate tenders in what concerns bidding behavior of the counterparts and induced allotment ratios in the primary market, functioning of the interbank market, and resorting to "standing facilities." Overbidding is again found to be inherent to fixed-rate tenders (without full allotment), but can be very mitigated under a variable-rate procedure. Furthermore, variable-rate tenders allow keeping some informational content of quantity bids, as opposed to fixed-rate tenders (again without full allotment).

The paper has also shown that (i) bidding mistakes are more harmful for banks restricted by collateral when the liquidity auction takes place at a fixed interest rate than when this rate is variable, (ii) credit rationing in the interbank market may lead to the placement of high amounts of liquidity with the ECB, reinforces the opportunity for fine-tuning operations, and enlarges the gap between the marginal rate and the minimum bid in a variable-rate auction, and (iii) a non-acute estimation of the system's liquidity needs has stronger implications for banks' expenses (to comply with reserve requirements) under primary market fixed-rate tenders than under variable-rate tenders. The paper also provides some rationale for the enlargement in the set of assets eligible for collateral purposes. Altogether, our results reinforce the use of variable-rate tenders as a means to provide liquidity to credit institutions, as opposed to fixed-rate tenders without full allotment, especially in times of pronounced market turbulence.

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